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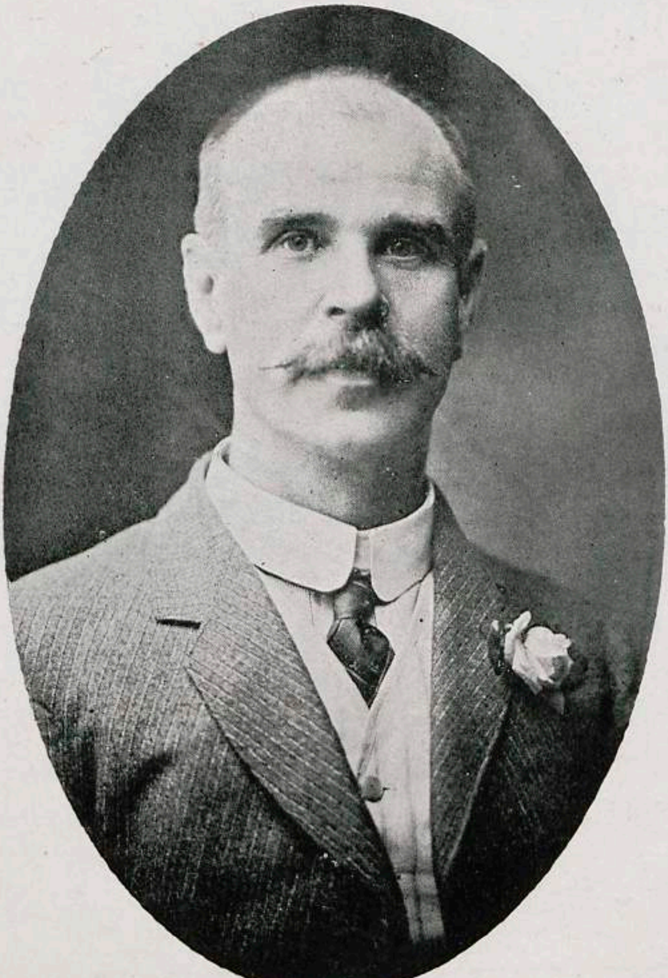

WILLIAM LESLIE, M.Inst.E.S., M.Inst.M.E.,
President 1911-1912.

VOL. 2. NOVEMBER, 1911.

PROCEEDINGS—WESTERN AUSTRALIAN INSTITUTION OF ENGINEERS.

PAPERS AND DISCUSSIONS.

PRESIDENTIAL ADDRESS.

(BY WILLIAM LESLIE.)

I feel my first duty to-night is to thank you for the high honor which you have conferred upon me in electing me to be the President of the Institution. I would feel very much happier if I did not in some measure feel the great responsibility which is attached to the office.

We, who are resident and practising our profession, on what, I might call, the engineering outposts of civilization, are somewhat differently situated from our confréres at home, and in older settled countries abroad, inasmuch as our time is so fully occupied in meeting the demands of construction and maintenance, that little or none is left for experiment and research. Nor have we the advantage of a professorial staff, attached to any of our public institutions, with whom we can confer on abstract questions. Under existing conditions we are frequently called upon to design, make accurate estimates of cost, and carry out new works, on modern lines, in little more than the time which would be allowed, in older countries, for full and complete investigation.

Naturally, under these conditions we have to depend a very great deal on the results which have been achieved elsewhere and which, fortunately, the press and the postal service—themselves engineering triumphs—make available for us.

That we have much higher day labour rates than any of the older settled countries—frequently double—that almost all our raw materials require to be imported, that the costs of our fuel and general supplies are very much higher, are all factors requiring very careful consideration, which will materially affect our decision, before the adoption of any particular design or plan, which may have been successfully carried out elsewhere under altogether different conditions.

Notwithstanding these disturbing elements we are expected in many instances to carry out in the same or less time similar works, or works which will answer a similar purpose, for the same, or less, expense than those carried out under much more favourable conditions abroad.

To enable us to do this, we require to keep ourselves in continual and closest touch with the doings of our brethren abroad, to study their difficulties, and how they overcame them, and to adapt and modify what is suitable for adoption to our own environment.

It is true we are seldom able for the amount of money allowed to give works of the same permanence as those produced in older settled countries for the same cost, but, generally speaking, the higher returns from the works compensate for the shorter life.

Sometimes as in the case of the Goldfields Water Supply Scheme, we have to step out a bit ahead to meet conditions which have not been met in other countries, but generally we are able to broadly follow what has been done before.

It behoves me, therefore, to make this acknowledgement of the great services rendered to us here, both by the leading Engineering Institutions of the world which have kindly consented to exchange Transactions with us, and also to the Engineering press for the full and complete descriptions and drawings they generally give of any important engineering work carried out. Without these, it would practically be impossible for us to design and build the works which this country requires and demands, and I take this opportunity of gratefully acknowledging the service.

The most modern text books are generally found to be a few years behind actual practice, and necessarily that is so, if the work is to cover a number of modern examples, but I believe no text book appeals to the Australian engineer like the matter published by the engineers who have actually been responsible for the design and carrying out of a particular work.

In his most interesting opening address last year, Past President James Thomson brought before you the main works which have been carried out in this State from its inception, and I am hopeful that, before our present session is over, we shall have some of these works exhaustively dealt with.

For to-night, I have thought it might interest you if I attempted a brief review of engineering progress during the last decade.

Looking out over the Engineering achievements of that period, there is much in regard to which we have had to make note.

First and foremost there is that stupendous undertaking being carried out by the American nation at Panama, the construction of the Ship Canal. Probably, both because it is a national undertaking, and because the best brains of that versatile nation have been retained to carry it to a successful conclusion, no work has hitherto been carried out in regard to which so much detail has been published respecting plans, methods, quantities and costs.

In all its earlier stages, indeed until some time after a substantial commencement had been made, this project was the subject of much adverse criticism both by those opposed to the Canal and those in favour of a sea level canal. As is not unusual, the loudest critics of the project were not engineers. Fortunately, the United States Government acted on the advice of its professional advisers to construct a lock canal, and we are almost certain to see the work brought to a successful conclusion within the present decade. Apart from its magnitude, this work is remarkable for systemization of construction and for the amount of collateral works, every branch of the profession of engineering being largely involved.

When we read, that in 1909 the slides on the sides of the excavation totalled round 4,000,000 cubic yards, and in 1910 over 2,000,000 cubic yards, we begin to appreciate the difficulties of estimating and the necessity for providing liberal sums for contingencies in our estimates.

In regard to Harbour Works the increasing dimensions of steamships, during the decade, have led up to the necessity for increased depths in navigation channels and Docks. Ten years ago, thirty feet in protected water was considered safe for anything. The equivalent of that to-day would be from 32 to 34 feet, and at no distant date the demands of ships will require provision to be made, for at least 35 feet at low water.

In a few days it is intended that the greatest shipbuilding triumph of the world, the White Star Liner "Olympic" will sail on her maiden voyage. It was a fitting opening for the new Alexandria Graving Dock in Belfast that this gigantic vessel should have been the first to enter the new dock last month, but it was ominous that while the width of the en-

trance of the new dock is 96 feet, the extreme beam of the " Olympic " is 92 feet 8 inches. The length of the " Olympic " is 882 feet 6 inches, with a register tonnage of 45,000 and a displacement of 66,000 tons.

Looking backwards for the last thirty years and comparing the contemporary liners engaged in the Altantic service with those engaged in the Australian service, it will generally be found that the Atlantic liners of one decade are the Australian of the next in point of size. If these comparisons are not to be disturbed we know what we have got to look forward to.

The rapid development in ships has caused many of the earlier dry docks in England to become obsolete, and the lowering of the cills, as well as the lengthening of some of the later ones, is at present under consideration.

Their proved reliability, moderate cost, and rapidity of construction have brought the sectional floating form of dry dock to the front, and quite a number suitable for ships of the largest tonnage have been built since 1900 for various owners including the British Admirality.

The adaptability, strength, and moderate cost of ferro-concrete construction have been appreciated by the harbour engineer, and numbers of deep water wharves and jetties have been constructed of this material. It will not stand the impetus of a 10,000 ton steamship any better than a solid concrete or stone quay will do, but it is much cheaper and requires little or no more for maintenance. In our own country where we have such splendid timbers as Karri and Jarrah suitable for superstructures, it may be, that we can confine ourselves to these for some time to come, but I think eventually, as in the case of timber bridges having had to give way to steel, so will timber wharves have to give way to ferro-concrete wharves.

For permanent sub-structures in sea water, no known timber is suitable. Steel corrodes quickly and cast iron is unreliable and costly. In ferro-concrete we have a reliable material which is comparatively cheap, which we can mould to our will, and if ordinary care is exercised in its construction to protect the reinforcement from corrosion, one that will last for generations.

In regard to Railways the substitution of electric traction for steam, for metropolitan and surburban traffic, continues to make slow progress, doubtless partly to the initial expense in connection with the provision of the new plant, and also the great changes affecting the terminals, but principally I believe owing to the indifferent results which have been obtained from partial conversion. Experience appears to indicate that little or no economy is obtained with a mixed service, but, where all the traffic, including goods, on the section is operated electrically, the results are much better than with steam.

A notable feature of railway construction was the completion of the Transandine Summit Tunnel connecting the railway systems of the Argentine Republic and Chili. This tunnel is 9,935 feet long and the formation level at the entrance, on the Chilian side, is at 10,481 feet elevation level. Although the work was commenced in 1906 at both ends, it was not until 1908 that it began to be prosecuted with vigor. Both drives met in November 1909. It is worthy of note the difference in level at the meeting was only three quarters of one inch, and the difference in line only two and three quarters inches. The actual chainage was only about 3 feet 10 inches less than the calculated chainage.

In Waterworks, the conservation of streams proceeds apace all over the world, particularly for irrigation purposes.

A notable work of this class, at present under construction, to which I would like to refer, is the construction of the Barren Jack Dam in New South Wales. This is a curved dam 784 feet long on the crest, and 240 feet in height with a capacity of about 33,380 million cubic feet. When the dam is full to the crest the water will be backed up for some forty miles. When completed it is expected the cost per acre foot of water stored, will be amongst the lowest on record, always excepting the Roosevelt Dam in America.

I would like here to urge upon our own Government, the immediate necessity for prompt action in respect to the resumption of land already alienated on rivers where conservation of water may be practicable, and also the non-alienation of similar lands at present in possession of the State. I would like also to urge upon them the necessity for a better and a much more liberal water supply for the Metropolitan District of Perth.

It is also very desirable that our very meagre knowledge of the artesian and sub-artesian supplies of water in our agricultural districts, should be supplemented by systematic boring, under a plan to be formulated by the Government Geologist. Reliable information as to the presence of water, its quality and its level would prove an inestimable boon to settlers in encouraging and guiding them to augment their supplies.

In regard to Sewerage, the Septic Tank system has been on fair trial in England, on the European Continent, and in America during the decade. The verdict might be summed up in two words "not proven." Some cities report a moderate success and others a moderate failure. The differences in the design of the tanks, and in the quality of the sewage entering them, make comparisons extremely difficult. One point I believe is proved, that is, that the tanks in the larger installations require cleaning out much more frequently than had been expected from the results achieved with the smaller ones.

Turning to the technical side, the record of the decade shows some notable advances, particularly in the development of the Steam Turbine and the Gas Engine.

It was only in the latter nineties that the Hon. C. A. Parsons built the experimental Turbine Steamer " Turbinia " and it was in September, 1899 that the first Turbine Steamer, the " Viper," was launched for the British Government. By 1907 the two large Cunarders " Lusitania " and " Mauretania " were equipped with steam turbines, driving quadruple screws, and approximating 70,000 h.p. in each ship.

For land work, the progress has been almost equally great and during the first half of the decade, turbines aggregating considerably over 3,000-000 h.p. had been put to work, in units ranging up to over 8,000 h.p.

A particular feature of steam turbine development has been that of the exhaust Steam Turbine. Where any considerable amount of exhaust steam is available from reciprocating steam engines, coupled with a copious supply of circulating water for the condenser, the waste can be converted into useful electric energy at a maximum cost of production of something under one farthing per unit, generally even lower than that figure and frequently saving the cost of additional boiler power.

In no branch of mechanical engineering has greater progress been made than in the development of Oil and Gas Engines and Gas Producers. The economy in working of internal combustion engines has been admitted from their inception, but until the beginning of the present century the sizes of the units were comparatively small, owing to difficulties of construction. At the Paris Exhibition in 1900, a 600 B.H.P. Gas Engine was exhibited, which was considered a great step in advance.

Later experience, bringing with it a better understanding of the heat stresses set up in the cylinder, as well as the working stresses, has eliminated all the earlier weaknesses, until at the present time Gas Engines of 1,000 to 1,500 h.p. with one cylinder are not uncommon.

It is to the development of the internal combustion engine that we owe the Motor Boat, the Motor Car, the Aeroplane. High rotative speeds and improved materials have made it possible to get engines weighing about four or five lbs. per h.p. In the case of the Gnome engine, I think it is about 3½ lbs. per horse power.

It was recently announced that an 8,000 ton cargo steamer is at present building for the Hamburg-American line, which is being fitted with two sets of internal combustion engines of the Diesel type, each set being 1,500 h.p.

In gas producers, the unit sizes is now up to 1,000 h.p., and the solution of the problem of the use of bituminous fuels in gas producers is prac-

tically accomplished. In the adoption of gas engines an important consideration appears to be the production of bye-product in the form of sulphate of ammonia. Plants have been at work for some years past where the proceeds from the sale of sulphate of ammonia produced have nearly paid for the whole of the fuel. The cost of the recovery plant is, however, an important item. It appears to be an accepted factor that the total power of the producers must be in the neighbourhood of 2,000 h.p. with a good load factor to justify the installation of an ammonia recovery plant with a Gas producer plant.

In 1901, on the initiative of the Institution of the Civil Engineers, The Institution of Mechanical Engineers, the Institution of Naval Architects and the Iron and Steel Institute, a committee was formed to take into consideration the advisability of formulating some standards for iron and steel sections. It had for many years previously been recognised that the number of sections in use had grown much beyond all necessity. The committee reported favourably on the proposal, and an Engineering Standards Committee, representative of these four Institutions and the manufacturers, was appointed under the Chairmanship of the Institution of Civil Engineers. It was found that the diversity of sections, and also of specifications in use, were the cause of considerably increased cost of production without any corresponding advantages, and that the manufacturers had to considerably limit their stocks for immediate delivery, manufacturing as they were for so many purchasers with different views. As a consequence, orders were regularly placed for large quantities of foreign manufactured sections, where stock deliveries were required.

As the work of standardization proceeded, its necessity, and the necessity for extending it, became more and more apparent. The co-operation of the Institution of Electrical Engineers was invited, and some eight Sectional Committees are now working under the General Committee. The work undertaken to date includes the standardization of sections and tests for materials used in Ship Building, Bridges and Building Construction, also of Railway and Tramway Rails, Locomotives and Railway Rolling Stock, Screw Threads and Limit Gauges, Pipe Flanges, Portland Cement, Cast Iron Pipes and Electrical Plant. The Sectional Committees are all under the Chairmanship of an expert, and, before final adoption, all their recommendations are subject to the review of the General Committee.

In 1902 the Home Government nominated engineers for the various committees and contributed substantial financial assistance. The services of the National Physical Laboratory have been freely rendered both in investigations and in verification of the British Standard templates and gauges. Various sets of standard gauges have been deposited at the Laboratory and are available for manufacturers throughout the country for the purpose of checking their working gauges. In 1907

about six and a half millions of tons of steel were produced in Great Britain, the greater part of which was rolled into sections and plates to which the standards and templates have reference.

In regard to rails, where the British Standard has been adopted, it is now one of the simplest commercial operations to purchase the best rails—either railway or tramway—with all the assurance that the quality and section will be correct. When the committee commenced its work there were in existence over seventy different sections of tramway rails in England alone. These have now been reduced to five with their corresponding sections for use in curves.

Not the least valuable work of the Committee has been the standardization of pipe threads. Hitherto considerable difficulty has been experienced abroad with the variation in the threads on different makers' tubes. It is agreeable to know that in the future one will be able to reject tubes which are not screwed to the British Standard.

From the Standardization of sections, the work has developed into the standardization of machines, and at least five distinct locomotives have been standardized for the Indian Government, leading to a very considerable cheapening in the cost of production. It is to be hoped that the standardization of machines will be proceeded with, only with the utmost caution, as being a dangerous bar to further progress in a standardized machine. Standardization and interchangeability of parts in all machines, certainly, but not standardization with the limitation of design, unless it is to be conceded that we have reached the limits of our ingenuity on any standardized machine, because, if foreigners can improve on our standard we must then abandon its manufacture or alter the standard.

The introduction of high speed tools during the decade has revolutionized machine tool design and the adoption of the new tools has led to a considerable cheapening in the cost of production with the ability to pay higher wages.

The main features in the new tools are, the ability to take heavy cuts at high speeds and the facility with which the feeds and speeds can be changed. It was continually found with the older style of tools that where a workman was employed operating a machine tool on work requiring light and heavy cuts at varying speeds and feeds the changing of the speeds and feeds by the cumbersome methods of belt cones was neglected and consequently the light cuts were frequently taken out with the same speeds and feeds, thus wasting considerable time. In the newer machines this has been remedied by the introduction of speed and feed gear boxes, by which any range of speed and feed can be instantaneously obtained by the simple pulling of a lever. About the beginning of the decade the old system of having long parallel lines of shafting driven by one main steam engine began to be abandoned in favour of a system of

grouping the machines and driving each group from one line shaft with an electric motor of constant speed. This was a great improvement on the older method but grouping is only resorted to now in the case of the smaller machines. All the larger tools being driven by separate motors attached to the machines. When required the motors are constructed of the variable speed type. Amongst the advantages of the independent drive are, increase in output due to the decrease of friction, the ability to work the tool up to its limit conveniently, and an improvement in the quality of production due to the steadier running. There is also the advantage that overtime can be worked on one particular machine without requiring to run the whole shop shafting.

The question of extensions of plant and positions for placing machines in the shop is much more easily determined with the adoption of the separate drive.

It is perhape a popular belief that high speed tool steels are very much harder than carbon tool steels. I believe that such is not the case. They are frequently not so hard but they have the quality of retaining their hardness and tenacity at the temperature of a dull red colour whereas the carbon steels become brittle when hard, and lose their temperature long before they reach a dull red colour.

Before I conclude I would like to make some reference to the education and training of apprentices. It is admitted now, I believe, that during the last twenty years or more the same care to give a practical training has not been maintained, as was the case previous to the introduction of so much machine and template work. The scope of the apprentice was narrowed in the largest works and the extraordinary growth of large works had in a great measure eliminated the smaller works where the training and experience given was more varied and useful to a young man. Technical training was only for the few, and the choice of men for the leading positions was limited accordingly. Fortunately this has all been changed and technical colleges and schools are now brought within reach of the poorest at all the principal centres. Even in our State our Technical Schools are doing good work which we must recognise.

It is not of course to be contended that an engineer can be trained in a technical college or school alone, but he can be taught a full acquaintance with the materials with which he is called upon to work, and also the elements of design, quite sufficient to give him that interest in his profession which will carry him far if he is ambitious and resolute in his determination to succeed.

In opening this, the second session of our Institution, I can confidently express the hope, because I have the confidence, that it will be fruitful of good work to us all. It is true in a small community like ours with its limited scope, we cannot hope to produce engineering giants of world wide reputation. It may be true that our modest attainments may not always meet with that recognition and deference which we ourselves consider to be their due, it may also be true that each of us may believe that we are capable of doing something very much better and greater than that which falls within the scope of our daily duties, but assuredly it is true that the best evidence of a man's capacity for doing better work is ever the way in which he does the work which lieth at his hand.

SOME GEOLOGICAL CONSIDERATIONS

AFFECTING

THE ARTESIAN WATER SUPPLY OF WESTERN AUSTRALIA.

(By A. Gibb Maitland*)

In addressing the Western Australian Institute of Engineers, I am painfully conscious of the circumstance that, although professionally trained as an Engineer, my acquaintance with the subject is in the main theoretical. However this may be, some of my multifarious investigations carried out over a period of nearly a quarter of a century, have been in a field, in which some members of my profession attempt to blend the science of geology, with the mechanical art of engineering; viz.—the subject of artesian water, which is of such vital importance to a country of the geographical configuration of Australia.

As you all know the investigation of subterannean waters is a specialised branch of geology, known as hydrology, and for a correct understanding thereof requires a more or less detailed geological survey, especially of the sedimentary rocks.

The artesian water supplies are possibly in the districts in which they are known to occur, one of Western Australia's most valuable assets. To the engineer, therefore, nothing is of more fundamental importance than a thorough understanding of the geological conditions under which artesian water occurs. The first step in connection with the utilisation and conservation of the artesian water resources of the State is the determination of the areas in which the supplies occur, and their extent; here it is that the purely geological considerations which govern the situation are encountered. At the same time, a summary of the geological conditions affecting the artesian water supplies of Western Australia can give no more than the barest outline, for it is merely possible for me to touch the fringe of the subject within the limits of the time at my disposal.

The known geological formations of the State consist of three distinct groups, viz:—

i. The Crystalline, Schistose and Metamorphic Rocks of Precambrian and possibly Archaean Age, which according to the present state of our knowledge occupy fully one half of the superficial extent of the State.

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*Government Geologist, Western Australia.

ii. The Sedimentary Beds, which range with many blanks from the Cambrian to the most recent and

iii. The Volcanic Rocks which are so largely developed in the northern portion of Western Australia.

It is, however, the Sedimentary Rocks that are of any value from the point of view of artesian water.

The results of boring operations in the State have revealed the fact that the bulk of the artesian water supplies are drawn from Carboniferous and Cretaceous strata, to which may be added the yields from what are believed to be Tertiary and Recent Beds. Artesian water has not only been searched for where it was likely, as well as (under protest), in one case, in granite, where it was impossible.

In the year 1885, Mr. E. T. Hardman, who at that time occupied the post of Government Geologist, in an official report dealt very fully with the question of supplying the city of Perth with artesian water, and after describing the principles of the construction of artesian wells, and the local geological conditions, concluded that it would be hopeless to expect an overflowing supply of water anywhere in the Metropolitan area. The conclusion is the only one which could be legitimately arrived at so long as it was assumed that the water carrying strata must be arranged in the form of one of those fanciful basins, sections of which have done duty for many years in geological manuals. Recent observations have shewn that this condition rarely obtains in nature, and that in all the important artesian areas, the porous beds are so arranged that there is only one side of a synclinal trough present and the imprisoned water has abundant facilities for escape at a much lower level than that at which it is received.

Before going much further into the subject it will be necessary to answer the two questions, viz.—What is artesian water ? and, What are the conditions which govern its occurrence ?

Artesian water then may be defined as that portion of underground water which is confined in the earth's crust at a lower level than its static head, and which will rise if encountered by a well, or other natural or artificial opening, affording an outlet.

Briefly and generally it may be said, that the conditions which govern the occurence of artesian water are as follows :—

1. There must be a continuous stratum sufficiently porous to absorb and transmit water.

2. There must be less porous or relatively impervious beds so situated that they confine the water so collected.

3. The altitude of the underground water at the source must be high enough above the surface of the well or bore-hole to compensate for the loss of head due to frictional resistance and leakage, and

4. The rainfall in the region of the outcrop must be ample, and that portion which enters the porous stratum must be sufficient to ensue a steady and abundant supply of water to the well or outlet.

The above fundamental conditions are simple and easily understood, though it is only fair to add that in actual practice, they are very often associated with complicated problems.

Western Australia possesses a large tract of country, which geological investigations, coupled with actual boring operations, have been shewn to be artesian water-bearing. Artesian water has been found in the Eucla, South-West, North-West and Kimberley Divisions, and as each of these districts present somewhat different geological characteristics, it will be convenient to describe each separately, and thereafter deal with certain broad questions which naturally arise in connection therewith.

Eucla Division.

A glance at any geological map of Australia shews an enormous expanse of Recent and Tertiary strata entering Western Australia on its eastern frontier, in the Nullabor Plains, and extending without any interruption as far as Israelite Bay. These strata consist of limestones associated with beds into which the rainfall is rapidly absorbed, and some of its discharged seawards in the form of freshwater springs. Where these strata have been pierced on the South Australian side of the frontier the section invariably shows from 300 feet to 500 feet of sandy water-bearing beds, of undetermined age, covered by a variable thickness of calcareous strata of both Older and Newer Tertiary age. The beds have a prevailing dip towards the Great Australian Bight and water rises in the bore-holes to a height equal to that of the sea level. The whole area of these beds in the Southern portion of Western Australia has been shewn, by actual boring operations to be more or less artesian water-carrying. Experimental boring operations were commenced by the Government at Madura, and a depth of 2,014 feet attained. The site of this bore lies about 110 feet above sea-level, at the Hampton Range, distant about 30 chains from the face of the escarpment, which is 350 feet in height. According to the cores, it appears that this bore pierced about 903 feet of limestone, The Eucla Limestone of Eocene Tertiary Age, beneath which were shales with occasional bands of dolomitic limestone. The bore did not however, pierce the floor of crystalline rocks upon which these beds rest. At a depth of 1,979 feet an overflowing supply of water at the rate of 1,000 gallons per diem, was encountered, whilst at a depth

of 2,041 feet, a further supply was tapped, which issued from a standpipe two feet above the surface at the rate of 5,700 gallons per diem. The borehole, however, did not pierce the whole thickness of the water-bearing beds, hence it is likely that if operations had been continued, a much more generous flow would have been obtained. A second bore at an altitude of about 300 feet above the level of No. 1, was put down at a spot 30 miles north of Madura, and carried down to a depth of 430 feet in the Eucla Limestone; this bore did not penetrate the underlying shales and sandy beds, and, of course, afforded no material information. The third bore was situated at the 337 miles 61 chains peg along the surveyed route of the Western Union Railway, at an altitude of 576 feet above sea-level. The bore hole was carried down to a depth of 1,372 feet, and passed through :—

Eucla Limestone	603 feet
Shales	667 ,,
Fine and coarse sand with hard bands and granite boulders	74 ,,
Granite	28 ,,

As would have been expected the results of this boring indicate that the beds are getting very much thinner as the inner margin of the Basin is approached. The Eucla Limestone having dwindled from 903 to 603 feet, whilst the underlying shales diminished from 1,138 to 667 feet. The first, or southernmost bore was not carried deep enough to pierce the sandy beds beneath the shales, hence there is no evidence available for comparison with their thickness in this section. The cores from No. 3 bore contained a series of fossils, which were submitted to Mr. R. Etheridge, of the Australian Museum, who acts as Hon. Consulting Palaeontologist to our Department. This gentleman reported that the beds beneath the Eucla Limestone, in No. 3 bore contain two of the most characteristic fossils *Aucella Hughendensis* and *Mac Coyella corbiensis* found in the Lower Cretaceous strata of South Australia and Queensland, which, as you are aware form the artesian water horizons of what may be conveniently called the Great Australian Basin. There is little doubt that the strata pierced in No. 3 bore are the equivalents of the Rolling Downs Beds as developed in Eastern Australia. In this bore sub-artesian water was met with in the sandy beds at the base of the formation, and rose to a height of 420 feet from the surface.

In the year 1908, Mr. C. G. Gibson, Assistant Geologist, devoted four months to an investigation of the geological features of a portion of the country lying along the route of the Western Union Railway, and the traverses this officer made enables the eastern boundary of the basin to be defined with a near approach to accuracy. The geological structure of the plateau indicates, that the sandy water-carrying beds below the Eucla Limestone do not outcrop near the margin of the basin, but impinge

directly on the older granitic and crystalline rocks, which are concealed from view. The sandy beds receive the larger portion of the water along this junction, which to the north must reach a fairly high average elevation. The catchment area of the Eucla Plateau (Premier Downs) is along the northern and eastern edge of the crystalline rocks ; this, which sends all its drainage on to the plateau conveys the rainfall directly to the porous beds along the outer run of the area. There are no rivers on this limestone plateau, which is the largest in Australia, hence all the water which falls theron, other than lost by evaporation is available for absorption by the strata upon which it falls. No estimates appear yet to have been made which enable the amount of water absorbed by the rocks of this plateau ; that such must I think be considerable, seems to be evidenced by the fact that the plateau is not drained by any rivers, which would carry off a certain portion of the rainfall, and that it lies within the 10 to 15 inches rainfall belt.

South-Western Division.

The most important portion of this division, when viewed in the light of the occurrence of artesian water, is what is known as the Coastal Plain, which practically extends from Lats 29° to 33° south. This plain is in reality a fringe of strata around the coast, and in certain localities its inner margin reaches an altitude of 600 feet above sea level. It is from the strata underlying the Coastal Plains that supplies of artesian water have been obtained.

The Tertiary Rocks of the Coastal Plain consist for the most part of partially consolidated shallow water deposits, which were laid down during the various periods of elevation and depression to which this plain would appear to have been subjected. These strata consist of sandstones, conglomerates, and thin shales, with occasionally incoherent sands and calcareous clays (? marls), in addition to ordinary river alluvium, raised beaches, and aeolian drifts, which latter are in places partially consolidated by the action of rain water. In the neighbourhood of Bunbury, these strata are associated with beds of basaltic lavas. The Mesozoic Rocks of the Coastal Plain consist chiefly of shales, sandstones, conglomerates, and limestones, lying horizontally upon the older crystalline and Palaeozoic Rocks. These Mesozoic Beds occupy a considerable area of the surface to the northward of Perth, and are in many cases met with in the strata beneath the Tertiaries during the course of boring operations.

Most of these beds exposed at the surface are of Jurassic Age, as determined by their plant remains ; they are seen to rest with a violent unconformity on the Carboniferous Rocks of the Irwin River Valley. No estimate can as yet be made of the thickness of these beds ; they have, however, been pierced by four bores in the Champion Bay District, the deepest being at Dongarra. The bore attained a depth of 2,111 feet when operations were stopped, owing to the capabilities of the boring plant

being exhausted, without the base of the Jurassic Rocks having been reached; there are thus over 2,000 feet of these beds in this locality. These Jurassic beds probably extend northwards, for in the deep bore at Pelican Hill, to which reference, will be made later on, strata high up in the Mesozoic series have been recognised between 1,200 and 1,500 feet. The importance of these Jurassic Rocks from the hydrological standpoint is their general permeability, which lends itself to the absorption and transmission of large quantities of water, whilst the great thickness of the formation gives it a large storage capacity.

The Jurassic Beds are overlaid to the north of Gingin by white, chalky limestone which passes downwards into a greenish glauconitic marl, resting on a clayey rock, which in all probability represents a clay-shale. The organic remains of the Gingin beds indicates the geological ages of the formations to be Cretaceous, which forms the principal artesian water-bearing horizon as developed in Queensland. This chalky limestone while on the whole highly absorbent, seems only to permit water passing through its mass very sparingly.

There seem very good grounds for believing that these beds are arranged in a series of folds of such a nature as might be expected to bring them near the surface at some points beneath the Coastal Plain, within the Metropolitan area. In some of the strata pierced by the boreholes in the city, fossils have been detected which indicate the presence of Lower Cretaceous Strata. Attention may be drawn in this connection to the fact that in the bores put down on the Royal Agricultural Show Ground, and the Hospital for the Insane at Claremont, a considerable thickness of solid crystalline limestone associated with glauconitic sands or sandstones was encountered. These beds are in all probability representatives of the Cretaceous beds, though on a lower horizon than those developed at Gin Gin. The important points, however, in connection with these discoveries, lies in the fact that, were boring operations carried down to greater depths beneath the Metropolitan area, it is highly probable that the water-bearing Jurassic beds which are known to underlie the Cretaceous Rocks would be encountered.

Whether the water obtained from such deeper sources would be likely to be chemically purer than that drawn from the present bores is one of those questions to which a definite answer can hardly be given. The water which percolates beneath the surface dissolves the soluble constitutents of the strata to an extent which appears to be in some measure dependent on the composition of the rock it traverses, the depth, and the time it remains confined. As a rule artesian waters seem to be less chemically pure than surface waters, for the reason that the further they penetrate the longer they remain embedded in the strata, the greater are the opportunities for solution.

Periodical chemical analyses of bore waters would throw a great deal of light on this aspect.

The first water that is drawn from an artesian well is naturally that which has been for a long time without any other means of escape, except the slow method of flow through the stratum in which it is confined. After the first draft upon the accumulated supply the amount which can be taken afterwards is governed by the rate at which the water can travel to the well from ever-widening limits, and as such presumably would travel less slowly through the rock, it would be less likely to be so highly impregnated with impurities. Such conditions prevailing it would *primâ facie* appear that with a constant draft on the supply there would be a tendency to less mineralisation, but whether the possible reduction would be of practical consequence is a matter of chemical investigation. Where water falls on and is absorbed by quartzose sandstones and allied rocks, and again reaches the surface without coming in contact with calcareous beds, such would naturally be expected to be relatively free from mineral impurities.

The Coastal Plain in the vicinity of Bunbury has been the scene of boring operations and artesian water obtained at shallow depths.

Southward from Point Casuarina and to the west of the town of Bunbury is a narrow fringe of basaltic lava, rising from beneath the sea-level, but forming no conspicuous elevation. To the Basalt succeeds a long irregular line of sand dunes, upon the highest point of which, Marlston Hill, the lighthouse is placed ; by far the larger portion of Bunbury, however, is built upon an extensive alluvial flat, the surface of which is raised but little above high water mark. Four bores have been put down in the Municipality. No. 1 bore at the east end of Stephen Street, and about half a mile west of the outcrop of the basaltic lava, was carried down to a depth of 30 feet. The drill entered the basalt after passing through ten feet of superficial deposits, and was carried down through it for a further distance of 20 feet, when operations were abandoned. The section in the bore at the Bunbury Brewery, below Marlston Hill, showed the basalt to be in the form of a bed, which in this instance proved to be 97 feet thick, resting on clay, though boring operations were not carried deep enough to show whether the clay was a thin layer dividing two individual lava flows, or was the floor upon which the basalt was laid down. During the last 10 or 12 years a good deal of boring has been carried out in the beds underlying the Coastal Plain in the Champion Bay District. There have been in all six fairly deep bores, the deepest being at Dongara, which had been carried down to a depth of 2,111 feet. This bore passed through 95 feet of calcareous strata belonging to the Coastal Limestone Series, and then penetrated over 2,000 feet of what are believed to be strata of Jurassic Age. The beds consist chiefly of sandstones, many beds of which are of exceptional porosity. At a depth of 149 feet water was

met with in a bed of sandstone and stood at 17 feet from the surface; on further boring to a depth of 935 feet the water rose to within 2 feet 6 inches of the surface, and when operations had reached 1,023 feet, in a coarse, grey sandstone, the water rose to the surface. The first overflowing supply, however, was encountered in a micaceous sandstone at a depth of 1,260 feet, the yield being 128 gallons per hour. This flow increased to 240 gallons, at a depth of 1,327 feet, the water issuing from a bed of micaceous sandstone. A supply of fresh water flowing at the rate of 3,600 gallons per hour, was met with in a micaceous shale at 1,384 feet; its temperature was 98° Fah., and it rose to 22 feet above the surface. Salt water was met with at 1,478 feet, and at 2,111 feet above the surface, the yield was 216,000 gallons per diem, the temperature being 104 degrees F.

The bore ran for four years, when it is stated to have become choked by rubbish. This very important bore did not reach bed-rock, owing to the capabilities of the boring plant being exhausted. Boring operations were continued 8 miles to the eastward at Yardarino, and when this bore hole attained a depth of 1,607 feet it became impossible for it to be deepened. This bore, however, yielded a supply of artesian water which overflowed at the rate of 589,000 gallons per diem from a bed of sandstone 166 feet thick, penetrated at a depth of 1,441 feet. The flow from this bore, however, was not maintained, and after a few years the water level had been lowered to such an extent, that by putting in a line of pipes in the bed of the river, about 16 feet below the mouth of the bore hole, a good supply of stock water was obtained.

The geological structure of this portion of the Coastal Plain shows that the strata are arranged in the form of a truncated basin as is nearly always the case in most important artesian water areas.

The North-West Division.

A considerable portion of what may for convenience be called the Coastal area of this Division is of considerable importance, economically, by reason of the fact that artesian water has been found to occur over a very wide area, and in consequence of the discovery of which the stock-carrying capacity of this excellent pastoral district has been materially increased. This area extends, so far as has been determined by such geological mapping as has been carried out, from the mouth of the Murchison River to somewhere about North West Cape, thus covering about 6 degrees of latitude, with a maximum width of over 130 miles.

The valley of the Gascoyne River from its mouth to a point a few miles below its junction with Dalgety Brook, affords a complete section of the whole of the strata which are of any importance from the point of view of hydrology, hence a few moments may be devoted to a consideration thereof in order that many matters which follow may be made clear. The strata occurring in the valley of the Gascoyne River consists of re-

presentatives of the Palaeozoic, Mesozoic, Tertiary and Post Tertiary Age, all of which are important from the hydrological standpoint.

The basal beds of the Palaeozoic strata, which it is of importance to note, carry a considerable portion of the artesian water in this portion of the State, have been carefully examined, between the Shipka Pass and what is known as Noondilyie Fish Pool, though a great deal yet remains to be done in the direction of more detailed investigations. The beds consist of conglomerate, sandstone, shale and limestones, the organic remains in which are sufficient to demonstrate the precise geological horizon to which the strata belong. When viewed broadly, the beds are found to have a very gentle dip to the westwards, which carries them below the level of Sharks Bay. These beds have been pierced in the experimental bore put down at Pelican Hill (Bibbawarra) near Carnarvon, which had been carried down to a depth of 3,011 feet, though owing to difficulties connected with the boring plant, it was not found possible to continue operations until the base of the Permo-Carboniferous Series (the water-bearing rocks) had been reached. The record of this important bore showed that :—The first 150 feet comprise clays, and limestones, of Newer or Post Tertiary Age ; Middle Tertiary calcareous clays and shales were passed through to a depth of 1,238 feet ; Mesozoic (and possibly cretaceous) clay shale and glauconitic sandstone, down to 1,361 feet ; whilst the balance of the beds 1,650 feet in thickness, consisted of limestone, black shales and sandstones, which the organic remains proved to be of Perno-Carboniferous Age. The limestone cores have yielded *Spirifera Aviculopecten*, *Anthracoptera* and *Favosites* identical with those occurring in the beds outcropping about 130 miles inland.

This Bibbawarra bore is of interest owing to the fact that it yields an overflowing supply of artesian water, drawn from a bed of sandstone, 448 feet thick, which forms the lowest of the Permo-Carboniferous Rocks penetrated. At a depth of 2,611 feet the bore yielded a supply of 300,000 gallons of water, but when it had attained its present depth of 3,011 feet, the supply increased to 520,000 gallons per diem, and there is no doubt that had it been possible to continue operations until the base of the series had been unequivocally reached, a much more generous flow would have been obtained. This bore hole is also of some importance from the fact that it gave experimental demonstration of the conclusion which had been arrived at from scientific investigation, that artesian water would be found in this portion of the State, and furthermore its success has led private enterprise to do its part in embarking in a policy of water-boring and the better utilization of those areas of pastoral country which make such an important asset in this portion of Western Australia.

What may be called the Kennedy Range Sandstones and the beds lying at the base of the Permo-Carboniferous Rocks are with minor exceptions well adapted for the absorption and transmission of large

quantities of water, and in addition these sandy beds attain considerable thickness. The structure of these beds is (omitting all minor details) that of almost one half of a synclinal trough, the eastern rim of which is at a considerable altitude above sea-level. The water supply of these beds is received along the continuous outcrop, which forms the catchment area from the head of the Murchison to the Yanarrie Rivers. The country to the eastward of this is made up of impervious crystalline rocks, which send all their drainage to the eastward, conveying the rainfall directly to the outcrop of the water-bearing beds, which forms a wide belt along the margin of the area.

The strata forming the Kennedy Range consist of fine grained sandstones, which are practically horizontal, or with so low a dip as to be scarcely perceptible in a single section: the sandstones attain a considerable thickness. They have been so denuded that the Valley of the Lyons forms a hugh ditch along the inner edge of the sandstones, which aids in conveying to and keeping the water in the Kennedy Range Sandstones.

The area over which the artesian water carrying strata occur, has been indicated with as near an approach to accuracy as has been found possible, upon the two geological sketch maps, which form plates 1 and 2 of Bulletin 26, published by the Survey.

According to the latest information available to me, there are over 20 bores in this North-West District representing an amount of boring equal to nearly 50,000 feet, and the total output from which is considerably over 5,000,000,000 gallons of water per annum. The system of boring for artesian water in this part of the State is capable of great expansion.

Kimberley Division.

The large area of sedimentary rocks, many beds of which are sufficiently porous to absorb and transmit water in the Kimberley Division, has led to some experimental boring on the part of the State. At Broome, a bore was put down to a depth of 1,362 feet, and yielded an overflowing supply of water at the rate of 142,000 gallons per diem, with a temperature of 103 degrees Fahr. Another deep bore at the 67 miles on the Derby-Lemard Road has been carried down to a depth of 2,129 feet, and yielded 140,000 gallons per diem, this water was derived from a limestone occurring at 1,040 feet, and of what is believed to be of Devonian Age, or older than the beds which yielded the water on the Gascoyne Valley. Two other bores were put down at Wyndham (Cambridge Gulf), one to a depth of 690 feet and another to 1,440 feet without striking water.

In his report on the prospects of obtaining artesian water in Kimberley, Dr. R. L. Jack, pointed out that artesian water might be met with in the area of Carboniferous Rocks occurring near Flora Valley. Since that report was written, the despatch of a party for the purpose of sinking

wells on the stock route between Wiluna and Sturt Creek, has afforded us an exceptional opportunity of gaining further knowledge of the extent of these beds. This work was carried out by my colleague, Mr. Talbot, during a journey extending over 426 days during 1908-1909; the results of these observations show that the so called "Great Sandy Desert" as indicated on nearly all the Australian maps is made up of sedimentary rocks, such as porous sandstones, alternatively with shales, disposed in such a way as to form an ideal artesian water-bearing basin. This country extended south from Flora Valley over 7 degrees of latitude to somewhere about the neighbourhood of Lake Disappointment. These sandy beds doubtless continue westward and form the low country which flanks the ninety mile beach, between La Grange Bay and Poissonier Point. It is of importance in this connection to note that the basal beds of the Carboniferous Series, which form the intake area of what may be called the Desert artesian area, outcrop along the northern flanks of the valley of the Fitzroy, where the rainfall is greater, and further the catchment area is in one or two instances crossed almost at right angles by the Lennard, and the Barker Rivers as well as some other creeks of minor importance.

Everything therefore points to the fact that boring in this as yet practically untested area may be carried out with a reasonable degree of confidence. Two bores have already been put down in the Fitzroy Valley at Upper Liverynga, one about three miles north-east of Mount Wynne, which yielded 7,000 gallons per day; the second bore, about three miles north-east of Liverynga Station, attained a depth of 70 feet and discharged 1,500 gallons per day. The few bores which have already been put down in this perhaps the largest of the Western Australian basins, proves that the occurrence of artesian water, is no longer a matter of theory.

General.

The great importance of water as an economic mineral is becoming more and more fully recognised on account of the direct dependence of the population upon artesian water supplies in certain restricted areas, that in bringing to a close what has I fear been a more or less dreary recapitulation of ascertained geological facts bearing upon the question, I feel it encumbent upon me to enter into certain other aspects which of necessity arise therefrom.

It is very generally recognised that an estimation of the quantity of surface waters can be determined by methods well known to engineers, but the determination of the total quantity of artesian water in existence cannot be even approximately arrived at.

Rainfall is disposed of in three ways:—evaporation, surface "rud off" and percolation; it is the balance that is left after evaporation ann

"run off" which is available for absorption by the strata upon which it falls and which is capable of being reached by wells.

I am only aware of one instance in which any observations have been made in Western Australia which enable an estimate to be arrived at as to the quantity of water available for absorption. Observations have been conducted by the engineers of the Public Works Department at two stations in the waters head of the Helena River; one near Midland Junction and the other near Greenmount. The westernmost station was situated on the outcrop of the porous strata of the Coastal Plain and the other on the crystalline (or impermeable) rocks. The observations at these two guaging stations extended over the years 1899-1901, showed that allowing nothing whatever for evaporation, there is a total possible absorption of a little over twenty-two thousand million gallons of water per annum. The geological conditions which prevail over large areas of the Coastal Plain demonstrate that rivers of much larger catchment than the Helena discharge their drainage into the plain and it is therefore reasonable to assume that a large proportion of the water from the catchment disappears beneath the surface, and helps to feed the artesian reservoir below.

The fact that we cannot arrive even approximately at the total quantity of artesian water in existence in the State, is not a matter of any particular moment, seeing that all that we are only concerned with is the quantity which when withdrawn annually is restored by natural means. When excessively drawn upon, artesian water, will in fairly arid regions be less rapidly replenished, because although the actual quantity stored therein may be enormous if more is withdrawn than the water-bearing beds annually absorb and transmit, a time must come when the flow of water over the surface will diminish or possibly cease altogether.

So far as I am aware very few observations have yet been made in Western Australia which will enable any very definite answer being given as to whether there is such a diminution in the supply of water from our artesian wells as to cause serious depletion.

In the case of two of the bores in the Government Locomotive Workshops Yard at Midland Junction; the yield of one diminished from 168,000 gallons per diem to 48,000 gallons during a period of three years from 1904 to 1908, and of the second from 1,500,000 gallons per diem to 600,000 gallons during a period of four years from 1904 to 1908. The first of these bores was 322 feet and the second 890 feet in depth.

At Bunbury two bores (which are connected), put down for the Railway Department to a depth of 70 feet yielded 96,000 gallons of water per diem, and by 1908 the flow had fallen to 86,400 gallons per diem.

Of course a lessening or even a cessation of flow would not of necessity indicate permanent exhaustion for there is always a come and go, as it were, in the level of underground water.

A diminished flow due to either (a) lateral leakage through superincumbent porous beds; or (b) the choking of the bore due to "creep," which may effect such soft and plastic rocks as clays and clays holes, or such loose rocks as sand and half coherent sandstone; (c) the accumulation of sand and fine mud, or some mineral product, and the wearing out of or defects in the casing, can be remedied by methods known to engineers.

A decrease in the flow due to the exhaustion of the head by a constant draft is irremediable; but the possibility of such can be minimised by shutting off the water at such a time as the supply is not required. In the event of a constant draft having any serious effect upon the supply, there should be a distinct and marked diminution of the pressure which only constant observations could detect hence the necessity for having accurate records kept of the pressure and flow of all bores, public and private, and the results properly tabulated. Hence it behoves those responsible for the conservation of our natural resources to see that reasonable care is exercised in the use of this most valuable asset of the community is to have it to draw upon for all time. In many districts the artesian bores are allowed to flow continuously uncontrolled, thus wasting a large proportion of the water, which can in the absence of a healthy public opinion on the matter only be prevented by legislative enactment.

If, of course, our artesian water supplies are limited, and there is no doubt that they are, then it is of course quite clear that such must be most carefully safeguarded. Artesian wells which are allowed to flow without restriction, tend to seriously lower the head of water, and if this depletion exceeds the amount which is replenished, then it naturally follows that a state of affairs may be brought about which cannot be faced with equanimity. The gravity of the situation depends largely upon the extent to which new wells are put down, their mutual interference, and the care with which bores now flowing are regulated.

The search for artesian water like all other forms of prospecting to be effective and economical must be carried out on those scientific principles which indicate the source, depth, amount and quality of the water likely to be obtained in the various geological formations as developed in different localities. This preliminary work is more or less a matter of geological investigation, and the first requisite is a more or less detailed geological map upon which the extent, nature and structure of the formations are defined with as reasonable degree of accuracy as the scale of the base maps employed will permit. . . . .

A good deal of this class of work has been accomplished in Western Australia during recent years, but the demands, therefore, at present exceed the capabilities of the Department.

The geological survey work having been carried out, it ought to be possible to produce maps showing the levels to which artesian water would rise by means of isopotential lines or lines of equal water pressure, though probably plans showing the underground contour of the water-carrying horizons in the different formations would be of more permanent practical value.

Another very important and essential part of the geological work in connection with our artesian water supplies consists in collecting as many records and cores as possible of all the bore put down in the State, and examining such of the cores as are available and interpreting the information they give in such a way as will render them of value for future reference or when embodied in official reports. In respect to pretty well all boring done by or with the assistance of the public funds, a fairly complete set of the cores now forms part of the collection stored in the Geological Survey Offices for purposes of reference. Whilst in the case of private bores thanks to the cordial co-operation of many of the boring engineers, and to the ready response to requests for information, fairly complete bore records which might otherwise have been lost are filed in the archives of the Department. Much, however, yet remains to be done before a really complete and accurate set of the Journals of private bores has been collected, for there is as yet no legal obligation on the part of the public to lodge such data with the Government even though the operations have been carried out on State property. Unless some steps are taken to acquire the information there is a possibility that a vast amount of valuable geological data, bearing upon the question of artesian water may be irretrievably lost.

Artesian water supplies are destined to play an important part in the development of certain portions of Australia that in 1908, it was suggested that a Consultative Board should be formed by representatives of the respective States of the Commonwealth, in order to deal amongst other things with the question as to whether the artesian water supplies of Australia were in danger of being seriously diminished and if necessary to advise as to the best means of combatting that contingency.

A good deal of valuable information was collected in Western Australia, and arrangements made to systematically investigate the whole question, but owing to causes which need not be specified the formation of such a Board has been left in abeyance.

Many years ago the United States Government, recognising the importance of having an exhaustive scientific examination made of the arid regions in the interior, with the ultimate object of ameliorating the conditions of life therein, appointed a commission consisting of geologists and engineers for the purpose. A perusal of the official reports of the commission shows what a vast amount of information, of more than mere local interest, has resulted, and the extent to which the appointment of this body was justified. Is it too much to hope that such a body will some day be brought into existence locally ?

This paper will not have been prepared in vain if it shall result in awakening the attention of engineers, and of those in whose interests they labor, of the perils which result from possible uncontrolled waste and dissipation, of that priceless heritage, with which Western Australia has been endowed, her artesian water supplies.

[For diagrams see end of book.]

ARTESIAN BORING—ITS INCEPTION AND PROGRESS IN WESTERN AUSTRALIA.

(By H. C. Castilla.)

In dealing with a subject of this description there is necessarily an enormous amount of dry detail which must be omitted, but which has given the engineers dealing with the matter much study. A volume could be written on this, incomprehensively technical to those not immediately associated with the subject.

At what date the idea of artesian boring in this State—or colony as it then was—first generated, I am unable to say, but there is no doubt a flow was accidentally struck some time during 1873, during a search for coal under the advice of Mr. Brown, then Government Geologist. The situation of this bore was somewhere near the Canning River, a few miles south-east of Perth, and close to the Darling Range. An extraordinary thing about the strike was that it must have been regarded as wholly unimportant by the author of the bore, and was completely forgotten, and was unknown to Mr. Brown's successor, Mr. Hardman, from whose pen a report dated 31st March, 1885 emanated, viz :—

"Artesian Wells and the principle involved in their construction."

"Artesian Wells—so called because they are supposed to have first been used in the province of Artois, France, can only be formed under the following conditions :—

"(1) The strata must assume a basin-shaped form.

"(2) There must be a series of strata consisting of an impermeable bed above, then a porous or series of beds, such as sand, sandstone or chalk and finally a second impervious layer through which the water accumulated in the middle bed cannot percolate.

"(3) In order that the water which collects in the porous strata may rise to some height above the surface at the point where the well has been sunk, it is necessary that the level of the water-bearing strata where it receives its supply from the rainfall shall be at a greater elevation than the highest requisite point of delivery.

"(4) To insure a sufficient supply from an artesian well the previous strata which holds the reserves of water must present a sufficient surface or available area to admit of an adequate amount of water being collected and stored away to meet the necessities of the given districts where it is required.

"It is obvious that under the conditions just pointed out the water supply will depend altogether on the area of the porous rock exposed, and on the amount of the rainfall of the district.

" But no such conditions as just laid down obtain here. We have no basin-shaped strata, we have no such alteration of the pervious or impervious strata showing a wide outcrop of the latter, nor have we any considerable elevation about Perth of the few thin outcrops of sand and sandstone which are met with.

" If the section of the country around Perth be compared with a typical section of a district in which artesian water is found it will at once be seen that there is no likelihood of obtaining a water supply on such principle here. As an example consider the London Basin. There water is obtained from the chalk and greensand formations which crop out at a considerable distance south of London and at a higher elevation striking from Rye to Horsham and exposing a large surface to absorb the rainfall. Toward London they are concealed by a more or less impervious strata the principle of which is the London clay, through which wells have to be sunk in order to reach the water stored up in the permeable or porous chalk or greensand, whence, by reason of the hydrostatic pressure due to high level, it rises readily to the surface.

" Another typical district is the Paris Basin in which the strata are essentially the same as the London Basin. There deep borings have been sunk through the tertiary formations (corresponding to the London clays) through the chalk and other members of the upper cretaceous rocks to the lower greensand. I need only refer here to the famous wells of Grenella and Passy carried down to the depths of 1,673 and 1,719 feet respectively. The outcrop of the greensand at Verdun, 150 miles to the South-East of Paris, is about 700 feet above the level of the sea while the plain of Grenella is but 104 feet above the level. The water here rose to a height of 122 feet above the ground; the point of saturation was, therefore, 1,474 feet below the outcrop of greensand.

" If therefore, this section be compared with that showing the geological structure of the country around Perth, it will be clearly seen how hopeless it would be to expect artesian water here—that is water which would overflow the well or borehole."

In the face of the development of the last 25 years it is difficult to understand how a recognised authority could have so emphatically expressed himself. The only conclusion I can come to is that there was much to learn about artesian supplies, and Western Australia, in this as in gold, presented new features.

At the risk of being tedious, I have given Mr. Hardman's report at length, but do not propose to do so with a much more important report from the pen of Mr. Harry Page Woodward, dated 7 : 3 : 92. Mr. Woodward was then Government Geologist.

Of this report it is sufficient to say that while Mr. Woodward agreed with Mr. Hardman on general principles, he differed with him on certain

details, which details in the event of subsequent developments proved vital. Mr. Woodward's reasonings were in favor of artesian water being found in the neighbourhood of Perth.

On the strength of this report a small hand plant of the Canadian pole rig type was procured, at a cost of about £400, and operations were commenced at the Midland Junction Workshops in September, 1894, and by January 1895 a depth of 500 feet had been bored. At 420 feet below the surface a flow of water was struck of 266,000 gallons per 24 hours.

The static head above sea level was 33.20 feet. and about the surface 20.20 feet.

Thus was the vexed question of the existence of artesian water in this State finally set at rest.

In quick succession other shallow bores followed in this locality. Mr. Morrison of Waterhall, Mr. Harper of Woodbridge, Mr. Gull of Bebo Moro, Mr. Hammersley of Locksley each ventured to have this new class of water on their lands, and the effect on irrigation was very remarkable.

The artesian basins of this State have been divided into three classes:

1. The proved artesian basins numbering three, in which overflowing supplies of water have been obtained by deep boring.

2. One large area as yet only partially explored and at present untested, over portions of which it is very probable that artesian or sub-artesian supplies will be obtained.

3. One proved sub-artesian basin in which large supplies of water have been obtained at a considerable depth, but which although rising many hundred feet in the borehole does not overflow the surface.

1. Taken in the order of their discovery comes the Perth, or more correctly, the South West Coastal Basin, which skirts the coast as a narrow belt from Geraldton at the north to the south Coast, a distance of 400 miles, and having a width which varies from 10 to 40 miles.

This basin has only been tested in three sections, viz.—from Geraldton to the Irwin River, between Midland Junction and Fremantle, and from Cookernup to Busselton. In the northern section the water with the exception of the Yardarino bore, proved to be too salt for human consumption. In the Perth section, with only one or two exceptions. the water was of good quality, but the striking point is that both quality and quantity vary very considerably, although the bores may be situated in close proximity.

In the Southern section, in the vicinity of Bunbury, the water is generally of good quality.

Between these three points the area has as yet been untested, but judging by the general character of the country, there is little reason to doubt that it is one continuous basin.

2. The second artesian basin, which may be called Western, extends from the Ashburton River in a southerly direction to the Murchison, a distance of 400 miles by from 50 to 150 miles in width. In this area, like the southern, the water in the extreme north is very salt, but improves in a southerly direction both in quality and supply. It is probable, however, that on the elevated tract of country between the Wooramel and the Murchison rivers only sub-artesian supplies will be obtained.

3. In the third or northern basin, which is situated around Derby and Broome, including a portion of the Fitzroy Valley, artesian supplies have also been proved to exist, whilst extending south-west, east and south-east, is a large unproved area of country, the rocks of which are identical, over which it is highly probable that artesian supplies will be obtained. As this tract embraces a large extent of the practically waterless interior, the proving of such a source of supply would be of extreme value to this State.

What may be called the south-eastern sub-artesian area covers the elevated tract of limestone country known as the Great Australian Bight, which extends westerly from the South Australian border for a distance of about 300 miles, and north and south for a distance varying from 150 to 200 miles.

In this area along the proposed route of the Transcontinental Railway line, boring has proved the existence of large supplies of good water, but these, owing to the elevation of the plateau, did not rise within 100 feet of the surface.

From this, it will be seen that large tracts of country exist in this State over which artesian supplies have been, and further supplies may be obtained, while vast tracts of almost waterless country have been rendered productive, and that further immense areas of desert will yet be made available for pastoral purposes, whilst to come nearer home, without this magnificent supply at our doors, a water famine must have occurred, in which case, Perth could never have obtained its present size or prosperity.

Boring Plants.

The methods now adopted for boring into the earth's crust in Australia, and for that matter all the world over, consist of three distinct varieties—the calyx drill, diamond drill, and cable drill. Each of these drills answers a particular purpose. We are now speaking of power dril-

ling plant, capable of going down to 3,000 feet or over. The ordinary hand drilling plant is only good for a few hundred feet—steam or other power is used for deep boring.

I will speak first of the calyx drill, or rather of the Davis calyx drill as it was originally called. This is an Australian system invented in Australia, and owing to this I have on two occasions lost foremen, on account of their special knowledge of the plant. One was engaged for England, the other for Russia.

It is useful in cutting through measures where a core is required.

The cutter of the drill is a cylindrical shell of steel, with teeth cut in it resembling the outer covering of a flower, from which the name is derived—viz. calyx.

By rotating quickly a system of jerks is caused which are imperceptible, and the cutter practically chips and saws its way through the ground. This cutter is about a foot or 18 inches long, and is screwed on to a core barrel—practically a tube, whilst above this is what is termed a chip cup—again another piece of tube.

Now the core barrel receives the core as it is cut, the inside diameter of the core barrel being the same as the cutter. The chip cup above the core barrel is for receiving the small chips or debris in cutting. This string of tools is supported from the surface of the ground by hollow rods screwed together, somewhat in the fashion used by a chimney sweeper when pushing his brush up a chimney, only the one is leading upwards, and the other down to water and minerals.

The hollow rods also serve a purpose—a stream of water under pressure is pumped through the rods to keep the hole clean and free from debris, returning to the surface again, the chip cup receiving the larger pieces, owing to the pressure of water upwards being greater around the core barrel and chip cup than above it, the rods being of a much smaller diameter than the barrel and cup below it. You will ask how the core is brought to the surface. The rods are raised and uncoupled but prior to this operation gravel is inserted into the rods as the surface, and the full pressure of the water is exerted to to force this gravel down into the core barrel, where it jams and grips the core. Held tight in the core barrel, by a twist of the drill the core is broken at the cutter. The whole is then raised to the surface as already stated, by uncoupling the rods. In the early years the calyx drill was employed in boring for artesian water and coal, the diameter of the bore ranging from 3″ to about 8″ in diameter. It is still used for boring through coal measures, but to a more limited extent for water, where a core is not required or necessary. It has had a longer life in this State than it probably otherwise would have had, owing to the necessity for carrying out the double purpose—geological information and water acquisition.

You will understand that the calyx cutter being of steel, when in meets stratas or formations harder than itself, there is trouble. This is where the diamond drill replaces the calyx. The operation of the diamond drill is practically the same as the calyx, the difference being it the cutter. The diamond drill cutter is a steel blank, but into it are embedded the diamonds or carbons, which rotates and grinds its way through the hardest of formations. You of course know these dimonds are not beautiful gem of adornment. They are black diamonds or pure carbon, and so far as I know only obtainable over a limited area in Brazil, South America. Either to their scarcity, or to trading manipulation, these diamonds have reached an excessive price. You will realise this when a diamond bit, say for boring 5″ diameter, would cost something like £400. Consider the risk of losing this bit, or tearing out some of the diamonds and losing them in the hole in the process of boring. Owing to the high price of diamonds, a system has been advocated of drilling through hard rocks with chilled shot and a blank bit. The chilled shot is placed at the bottom of the bore hole, the blank bit rotating over them under pressure, friction doing the rest with the shot in movement. This system has yet to prove its value against the others, so far as I know. Manifestly it would be useless in soft ground.

We now come to the cable drill, an American and Canadian system now generally adopted in Australia where cores are not required. This is purely a percussion drill pulverising everything it meets. A cable is used in place of rods as with the previous systems mentioned, and is suspended from a walking beam. The boring is done by heavy bits and tools suspended from the cable or wire rope. With a swivel the tools are made to turn a round hole. It would take too long to explain the variety of tools used in this process, but you would be struck with their great weight. It can get through practically the hardest rocks, and taking all things into consideration is probably the speediest and most economical process at the present day.

At the risk of digressing, I may state that in boring on the Goldfields the diamond drill is solely used, the core being of a very small diameter, requiring the minimum of diamonds in the cutter. Boring on goldfields is of great value in testing the ground and lodes compared to the great cost of sinking shafts.

The cable plan owes its rapid advancement to a set or string of tools as they are termed, consisting of chisels, sinker or jar bar, and set of jars.

The chisels are of two kinds—flat and side-cutting and of various sizes to suit the size of the hole required.

The side-cutting chisel is made with one edge straight, and the other slightly rounded so as to admit of its being close up to the side of the hole.

The cutting-edge is set in two sections with chisel points—one about four inches lower than the other. The vertical motion of the walking beam to which the cable is attached lifts and drops the string of tools, which weighs from 15 cwt. to 1 ton, on the bottom of the bore hole, pulverising the strata which is washed to the surface by a stream of water pumped down the hole.

This system has the advantage over the calyx or diamond drills in having no rods to uncouple or core barrel to employ and consequent delay necessary to their operations.

As it does not produce a continuous core, it is not in favor with our geological confreres.

The question often arises to what extent has the State benefited by the artesian boring carried out to date.

Doubtless, the greatest direct benefit has been in the pastoral industry in increasing the stock carrying capacity of comparatively small area which a few years ago were almost useless and thereby augmenting the capital of the country. There has been a very noticeable tendency on the part of the north-west squatters of late years, to invest surplus capital in the Metropolitan area, and in the farming districts. The inference is that without the augmented water supplies on the pastoral area by artesian bore these monies would not have been available hence the effect of the work on the development of Perth and suburbs.

Of the direct and economical effect on the Metropolitan water supply, my colleagues are in a better position to speak than myself. Speaking personally, though somewhat empirically, I have a strong prejudice in favor of certain bore water for human consumption. They contain the necessary chemicals for bone and denture. The fallacy that pure water, if there is such a thing in use, is necessary for health requires exposing and the sooner the public mind is enlightened on this point the better.

Some years ago when Claremont was supplied with hose-water, sundry of my foremen prevented their children drinking it and insisted on the use of rain water from the roof catchments. I insisted in a contrary course and I am not certain that the teeth of the children who have been drinking rain water compare most unfavourably with those who have been using the bore.

The disappointing feature of these bore waters are their effect on irrigation.

With the exception of the shallow—Guildford bore and the Zoological Gardens bores—I know of no others fit for irrigation. The Leederville valley bore, no doubt, was, but it is wholly required for the Metropolitan area.

To what extent this can be remedied is a problem for the future, a problem, however, which is now being earnestly tackled in Queensland and New South Wales.

In those two States when artesian water was first discovered, something like a boom in boring took place, and the waters were utilized for irrigation ; at first no harm resulted, but in a few years it became apparent that, as was also the case in India, much land was being destroyed by the indiscriminate use of unfit water.

The generous supplies that were to have been the panacea for all evils agriculturally not only failed to fertilize, but actually to ruin what had hitherto been good land, making further cultivation impossible. It was an awakening resultant on much loss.

For some years no steps were taken to provide a remedy, but awakened by the enthusiasm of a certain chemist and investigator two years ago, the Government of New South Wales commenced a series of experiments on land previously sterilized by unfit bore water. It took the shape mutually of treating the bore-water with nitric acid before utilizing it for irrigation.

The results have been somewhat startling, but so encouraging that the operations are being continued apparently with good results.

It behoves us in this State to keep ourselves fully in touch with these operations as if the difficulties in the way of use of our bore-water for irrigation can be overcome, the benefit to the State may be incalculable.

Discussion.

Mr. Hugh Oldham, in complimenting the authors of the two papers under discussion, stated that it was impossible to exaggerate the value to hydraulic engineers of the research work which had been done in Australia by such men as Dr. Logan Jack, Mr. H. Y. L. Brown, Mr. Woodward, and Mr. Maitland, the author of one of these papers. The onus of indicating the extent of artesian areas falls, of course, upon geological experts. One point referred to by Mr. Maitland is specially interesting : that is the fact that in none of the basins on the coastal face has it been possible so far to reach the bottom of the sedimentary strata comprising the artesian horizons. The fact that in all cases where the sources of horizons have been encountered the increase of water pressure has been evident, indicates that the sources of supplies are obtained from the Anticline, and not from the Syncline ; that is to say, the intake is apparently on the coastal side of the axis of the backbone of intrusive Plutonic rock. Mr. Haynes had referred to the use of the term basin, suggesting that it was only a figure of speech. This is so, as, at any rate in the coastal areas, there is only one elevated side to

the artesian area, there being a natural escape somewhere out in the Indian Ocean. Regarding the question of depletion of the artesian sources, a considerable amount of investigation had been carried out under the speaker's direction, and cases had been referred to the Department where there were manifest diminutions of flow. In all cases so far the loss had been traced to local causes, and there was nothing to indicate any depletion of the sources. An experiment conducted at Claremont in the way of testing the effect of flow upon loss of head produces data which, where plotted in a curve, indicated that a bore would always return to its original static head if closed down, and further, that when the period of flow was for an extended period the time required to recoup the head was practically the same, as, for instance, a flow of six weeks as against six months. The small basin at Collie was interesting as apparently approaching much more closely to the ideal form than others in the State. The artesian water in this basin was shallow, so shallow, in fact, that the drainage water in some of the mines appeared to come from this source. Members would appreciate the difficulty which such a state of affairs would produce upon unwatering propositions.

MR. F. W. LAWSON said that the subject brought under notice by Mr. Castilla and Mr. Gibb Maitland is one of the most important that can be considered in connection with the utilisation of our arid districts for economical productive purposes. The actual date of the first discovery of artesian water and boring (excluding the accidental discovery in 1873) appears to be 1879, at Kallara, between Bourke and Wilcannia, in New South Wales. The first bore in Queensland to produce sub-artesian water was one near Cunnamulla, whilst the first real artesian bore was at Back Creek, in which water was struck on 28th. November, 1887; so it would appear that some considerable time elapsed before our State followed in the wake of the two States previously mentioned. However, there can be no doubt that the finding of artesian water in 1894 ought to be placed on record as one of the events which will in the near future do more than the discovery of gold to advance the industries which mean so much to any State. Dealing with Mr. Castilla's paper from the standpoint of construction of bores and the machinery used for this purpose, it would be of interest to know the cost of drilling with the three systems mentioned, as it had been the experience of the speaker that the cable drill has long since been looked upon as the only system to be used in tried ground, the diamond drill only being used where the core is required for geological information. The tools required for a cable drilling plant are very extensive and an ordinary outfit requires at least 25 to 30 different joints. It is in the use of these that the skill of the foreman is shown. By the use of this system bores have been sunk to a depth of 5,045 feet in Australia. In this matter it is well to consider the most suitable sizes for casing for deep bores and it would appear that for ordinary irrigation purposes that a 10″ casing should

be carried down for about 300 feet and 8″ casing to 700 feet, after which 6″ casing is used. The advantage of this method is the reduction in friction on the smaller size of the casing. If it is not possible to carry the 6″ casing right down to the full depth 5″ casing may be used, but it is preferable if possible to carry the 6″ casing down as far as possible. Sometimes the larger sizes of casing are withdrawn, but this practice is not desirable, as in the event of the bore having to be shut down the sub-soil water may find its way to the surface through the disturbed ground, whereas if the casing were left in there is little possibility of this happening. In regard to the use of bore water for irrigation, there does not appear to be as yet any certainty about the suitability of bore water for growing cereals, but there is an unlimited field for its use for stock purposes and for certain classes of fruit trees. I am not sanguine enough to hope that bore water will extend our wheat belt, but it will undoubtedly increase the carrying capacity of our cattle stations and if rightly used for this purpose great wealth must flow into our State coffers. There is an important point that the authors do not appear to have touched upon, but no doubt have particulars of, viz., the determination of the flows or hydraulic grade of the artesian waters. The time appears to be ripe for the accurate measurement of the hydrostatic pressure and the plotting of a curve or curves for each known basin. For this purpose the various bores should be closed down and the pressure of each taken by means of a pressure gauze. Further, it would be desirable for the intake beds of the artesian basins to be defined by a geological survey. The bores on the eastern side of the Darling Ranges are apparently fed from the rain which falls on the hills. It has been observed that some of the Australian rivers carry off as much as a quarter of the rainfall, while others only discharge 1.5 per cent., so that there is evidently some agency at work to account for this small flow. For some time past the discharges of some of the rivers of the eastern slopes has been observed by the writer, and the percentage o frun off has apparently been less than 10 per cent. of the rainfall on the average, and this percentage includes one permanent stream at least ; therefore, I think that it is safe to assume that the major portion of the rainfall on the eastern slopes of the Darling Range is available for use as artesian or sub-artesian water. In connection with the testing of artesian water for hardness, there has recently been devised a very simple method of examination of water for hardness by electrical methods,* and the adoption of this system would seem a most desirable step to obtain quickly in the field the hardness of the water obtained at various depths in any bore during construction. Recently a bulletin issued by the Department of Agriculture has been brought under my notice. This covered experiments with the water finder of Messrs. Mansfield and Co. and the experiments made with this instrument,

*Proceedings, Institution of Electrical Engineers, 1910.

the principle of which is quite simple and may be explained as follows :—If a copper wire be held near a magnetic needle, and its two ends connected to the two terminals of an electric battery, so that an electrical current flows in the wire, it will be found that the needle is deflected from its normal position, and it will remain deflected so long as a current is traversing the copper wire. If, however, instead of directly holding the wire near the magnet a closed metallic circuit be held near it, and a copper wire be placed near the current, it will be found on suddenly connecting the wire to the terminals of the battery that the needle is deflected ; the deflection is, however, only transient and not premanent, as in the last case. Here, when the ends of the copper wire are suddenly connected to the terminals of the battery, the current flowing in the wire induces a transient current in the metallic circuit, which causes the deflection of the magnet, and as the current is only temporary so also is the deflection of the needle. If, again, the intensity of the current be varied it will produce a temporary deflection of the magnetic needle. The same principle causes the deflection of the magnetic needle in the water finder when it is fixed on the surface where water is flowing below, with this difference—that here the inducing currents do not flow along a copper wire but are generated in the underlying strata. These currents, which are known to be generated by many causes, generally follow the course of a stream, that being the line of least resistance ; they then induce currents in the water finder much in the same way, in which the current flowing in the copper wire, as before mentioned, induces the metallic circuit ; and it is these induced currents that affect the magnetic needle, which consequently is deflected from its position of rest. The greater the underground flow the more rapidly does the needle oscillate. The whole efficiency of the instrument would seem to depend on the preference of earth currents to follow the path of an underground stream. It would appear that a certain amount of success has followed the use of this instrument and it would seem that it would be worthy of a trial in our shallow artesian or subsoil water bearing districts. Probably Mr. Gibb Maitland may be able to say something more regarding this instrument, which is a practical application of a well-known principle.

Mr. A. Gibb Maitland, in replying to the remarks and observations on his paper, said that he laboured under the very serious disadvantage of not having been present at the meeting at which the subject matter of it was discussed. In reply to the remarks of Messrs. Oldham and Lawson, my paper might have been much fuller, had I gone into great detail, into what might be called the severely scientific side of the broad question of artesian water supplies in general. The *raison d'être* of my paper, however, was to bring out such aspects as affect our artesian water supplies as more directly appeal to those members of the engineering profession who are called upon to demonstrate practically their value. Mr. Hugh Oldham remarks that in none of the bores which have been

put down on the Coastal Plain has it been possible to reach the bottom of the sedimentary series of strata which contain the artesian water horizons. When viewed broadly the geological structure of the Coastal Plain shows an ascending geological series southwards from the Murchison. In the railway station yard at Geraldton the old granitic floor "bed rock" was met with at 420 feet, and the granite penetrated for about 2 feet 6 inches, whilst at Busselton granite was reached at 653 feet, and at Newtown at 330 feet. The last bore put down by the Government, at Cookernup, 80 miles south of Perth, was carried down to a depth of 2,215 feet, when operations were discontinued in a bed of sandstone, without having been carried deep enough to meet bed rock. This bore yielded no water, possibly because it was not sunk deep enough. With, therefore, the local exceptions (Geraldton, Busselton and Newtown), in no case has the ancient floor of crystalline rocks been unequivocally reached anywhere on the Coastal Plain. As Mr. Oldham remarks, the intake area of the water-carrying beds of the Coastal Plain is on the seaward side of the escarpment of the Darling Range. It has been pointed out in the paper that up to the present time there is only one instance in which such observations have been made which will enable an estimate to be arrived at of the amount of the rainfall which is available for absorption by the permeable strata of the Coastal Plain. These observations demonstrated that over twenty-two thousand million gallons per annum of the rain falling in the watershed of the Helena River disappears beneath the surface between Greenmount and Midland Junction, and helps to feed the artesian reservoir below. It is much to be regretted that observations of the actual discharge of the other rivers crossing the Coastal Plain have not yet been made, so that a reasonably reliable estimate of the quantity of water absorbed by the porous strata may be arrived at. It has been pointed out that the supply of artesian water is derived from the rainfall percolating at the present time ; certain high authorities have recently promulgated the theory that artesian water supplies are derived from three main sources : (*a*) plutonic water which has risen from below ; (*b*) residual water deposited in the strata at the time of their formation ; and (*c*) some rainfall which percolated into the sandstones at an earlier geological time. The consideration of these theories being rather of academic interest, and somewhat outside the scope of this Institution, no further reference need be made thereto, beyond pointing to the observations of the engineers of the Public Works Department, to which I have referred, and which prove beyond all shadow of doubt that contemporary rainfall *does* add annually an enormous quantity of water to the strata of the Western Australian Coastal Plain. In regard to the question of a diminution in the supply of the Western Australian artesian wells, such as might cause a serious depletion in the head of water, cases were quoted of the bores in the Government locomotive workshops yard at Midland Junction, and those in the railway yard at Bunbury, where observations extending over a period of years

showed a most marked lessening of the flow. It was at the same time pointed out that a lessening or even a cessation of flow does not of necessity indicate permanent exhaustion. Mr. Oldham, the Engineer for Water Supply and Sewerage, however, points out that investigations have been carried out under his direction in this connection, and it cannot but be a source of gratification to have his assurance that such manifest lessenings of flow as have been detected can be traced to local causes, and there is so far nothing to as yet indicate any permanent exhaustion of the supply of artesian water. In my paper it was pointed out that if a constant draft upon our artesian water supplies had any serious effect such would be indicated by a distinct and marked diminution of the pressure, which could, of course, only be detected by constant observation, carried out regularly over lengthy periods, and the paramount necessity for having accurate records kept under Government control of the pressure and flow of all bores, both public and private, and the results properly tabulated was emphasised. In reply to the observations of Mr. Lawson, regarding the delimitation of the intake area of the various artesian water areas so far known in Western Australia, a great deal has already been done in this direction, and geological maps have been prepared and published of the Eucla, the South-West, the North-West, Kimberley and part of what may be called the Desert Artesian Area in the Eastern Division of the State, whilst only a week or two ago a new map of the country between the mouth of the Irwin River and Cape Leeuwin has been made available to the public for the special purpose of rendering assistance to the agricultural industry, for the possibility of the utilisation of much of our agricultural land is largely bound up with the question of its water supply, hence special attention requires to be paid to its needs. It, however, is much to be regretted that no artesian water is likely to be obtained over the major portion of it. Mr. Lawson, in his concluding remarks, directs attention to an instrument known as an automatic water finder. We all know that what is known as rhabdomancy, or the power of detecting the presence of water with the aid of a divining rod, dates back to the very earliest periods. So far as any scientific information goes, the power of divining has proved absolutely unreliable in those cases in which, from its very nature, it should have proved infallible. In respect to the efficacy of any mechanical appliance for water finding, I am quite unaware that water cannot be equally well detected by the exercise of more or less plain common sense in the direction of the compilation of reliable data, followed by logical reasoning. The mode of occurrence of underground water is of course entirely dependent upon considerations of geological structure, hence competent scientific opinion should, *caeteris paribus*, be of greater value than that of a "diviner" or even any mechanical appliance yet constructed. In thanking members for the cordial reception which has been given to my remarks, I can only repeat what I have already stated, that "The paper will not have been prepared in vain if

it shall result in awakening the attention of engineers and of those in whose interests they labour of the perils which result from possible uncontrolled waste and dissipation of that priceless heritage with which Western Australia has been endowed—her artesian water supplies."

THE STEAM TURBINE.

(By J. R. W. Gardam.)

It is now some twenty-seven years since the first commercial steam turbine was made by Messrs. Parsons, and though an immense amount of experimental work was devoted to the subject by that firm it was not until their patent rights became available to other manufacturers that the turbine reached the position it holds to-day ; in fact, the present-day machine may be said to have developed within the last eight years.

The steam turbine has many claims to consideration. Especially to be noted are :—

Its suitability for driving electric generators, air compressors and blowers, pumps, and other machinery best suited to rotary motion.

Its economy in steam consumption, particularly on pressures below atmosphere.

Its compactness and lightness, requiring very small space and slight foundations, which means large saving in cost of land, buildings, etc.

The absence of internal rubbing surfaces, enabling high superheat to be taken advantage of.

No internal lubrication, which accordingly renders the exhaust steam free from oil.

Its adaptability for utilizing the exhaust steam from other engines.

Its reliability, low maintenance and quiet operation.

Any of the above reasons may be the deciding factor in the selection of steam turbines in place of reciprocating engines, and though probably under 500 K.W., a high-pressure turbine would not be so economical of steam as a reciprocator, small turbines even down to 5 H.P. are used for purposes where economy of fuel is not as important as high speed, saving of space or convenience of operation. From 500 to 1,000 K.W. there is little difference, if any, between the steam consumption of turbines and reciprocators, but above that figure the turbine rapidly surpasses the best engine performance.

Comparisons in steam consumption are useless unless the exact operating conditions are fully known, but from the records that have been published on large units the advantage under practically the same conditions lies with the turbine by approximately 20 per cent.

The following records are comparable :—

With 175 lbs. steam 80 deg. superheat 28″ vacuum a kilowatt hour was obtained by an expenditure of 16.78 lbs. steam in a reciprocator and by 13.88 lbs. in a turbine. In this case the theremodynamic efficiency of the turbine was 69 per cent. according to the Rankine Cycle, which is the ratio of the B.Th.U. actually used to the amount theoretically available.

The principal reason for the higher economy in turbines is due to their ability to carry out the expansion of the steam more completely to a lower pressure than the mechanical difficulties of an engine will permit, due to the enormous volume of steam at the minimum condenser pressure. When it is remembered that steam at 29″ vacuum has a volume 5 times greater than at a 26″ vacuum the difficulties in the case of the reciprocator are apparent, in addition to which the same steam economy advantage is not attained, as the following table shows :—

Increasing the Vacuum from	Decreases Steam in Reciprocating Engines.	Consumption in Turbines.
15″ to 18	5.8%	6.2%
21	11.6	12.6
24	17.3	20.0
27	23.1	30.1
28.5	26.0	37.4

Principles of the Steam Turbine.

The principle on which any turbine works is the conversion into kinetic energy of the heat stored in the steam, and in order to obtain this the steam when allowed to expand, its pressure and temperature will fall, whilst its volume and velocity will increase. This kinetic energy transferred to a moving wheel produces the power required.

This transference of the energy from the steam to the moving wheels is achieved in one or both of two principles known respectively as the " impulse " and the " reaction " (Fig. 1). The main difference between the two being that in the impulse type the nozzle is fixed and the wheel moving in the direction of steam at half its velocity, no pressure drop taking place in the wheel itself, whereas in the reaction type the nozzle and wheel are one, the wheel moving in the opposite direction to the steam with the same velocity and the whole pressure drop taking place in the wheel itself.

In the " reaction " type steam enters the stationary blades, expands therein, and in doing so acquires velocity with which it enters the moving blades ; this acts on the moving wheel on the impulse principle, further expansion takes place in the moving blades, which energy is absorbed

on the reaction principle, this process continuing through all the stages. The steam being expanded in successive stages of fixed and moving blades, the whole drop of pressure taking place in the blades themselves, makes necessary a large number of rows of blades in order to minimise leakage by reducing the fall of pressure across any set of blades as small as possible, consequently the clearances must be made as fine as is safe, for naturally the steam prefers to take the easiest path, which is over the tips of the blades, rather than do work on the wheel. Thus to get the greatest efficiency, reducing the clearances to a minimum is unfortunately opposed to the necessity of making the clearances sufficiently large to prevent risk of fouling. It is accordingly necessary to make the shaft rigid and well-balanced to keep the bearings perfect and the cylinder free from distortion through heating, this last reason limiting the amount of superheat used. . . . .

In the impulse type the whole of the steam is expanded in fixed nozzles, which impart the velocity of the steam to the moving wheels. The moving blades are so designed that no drop of pressure takes place across them and consequently there is no tendency to leakage, thus enabling large clearances between the fixed and moving parts. The whole of the velocity of the steam may be expended on one wheel or may be divided between successive rows of fixed and moving blades imparting a portion of its velocity to each. This latter is called "compounding by velocity," and by its use the peripheral velocity is reduced without impairing the efficiency.

Another feature used for the same purpose, viz., to lower the peripheral speed, is that known as "compounding by pressure." In this method the steam is expanded in a number of steps each extending over only a part of the total pressure range, so giving at each stage only a part of the velocity.

Cellular and Drum Construction.

With "reaction" type turbines it is customary to use drum type construction, but in practically all "impulse" type turbines cellular construction is adopted.

The drum type is used for "reaction" machines on account of the pressure drop which takes place within both the moving and fixed blades, necessitating fine clearances, and since a large number of rows of blades is necessary the drum construction is the most suitable method of supporting them.

In "impulse" type turbines no pressure drop takes place in the moving wheels, and consequently there is no cause for leakage, and large clearances may be employed. A pressure drop, however, takes place between each side of the fixed nozzles and in order to reduce this

leakage to a minimum the nozzle diaphragms are carried down to the circumference of the shaft proper and in order to make trouble from fouling impossible the inner circumference of the diaphragm is bored slightly larger than the shaft and fitted with rings turned so as to present knife edges to the shaft, but which are so thin that should contact take place nothing beyond burring over would result.

The drum construction could be used for the impulse turbines, but is not so suitable, as the clearance at the circumference would afford a very much greater area for leakage than a similar area at the shaft.

Comparison between Reaction and Impulse Turbines.

The reaction type of turbines (Fig. 2) has inherently the following features which render its supercession by the impulse type almost certain, as the immense strides made by the latter in the past three or four years show.

Fine Clearances, which increase the risk of stripping necessary to reduce steam leakage across the tips of the moving wheels, caused by the difference of pressure on the opposite sides of the moving rows of blades. In the impulse type this difference of pressure does not occur and consequently the clearances can be made ample.

Dummy Pistons, which have to be set very fine to reduce leakage of steam past them are necessary to counterbalance the end thrust caused by the difference of pressure mentioned above. These are not required in the impulse type, as there is no end thrust.

Long and small diameter Shafts. On account of the velocity of the blades being nearly equal to the velocity of the steam, a greater number of rows of blades is required than in the impulse type, which has a velocity of blades only half that of the steam velocity. At the high pressure end the diameter of the spindle must be kept small, as the steam occupies very small volume at high pressure and is admitted all round the circumference, otherwise extremely short blades would have to be used and the leakage path would then be proportionately much greater. This smaller diameter again increases the number of rows of blades.

Governing on the reaction machines must be done by throttling, which is a loss not experienced by the impulse type, which cuts out more or less nozzles to suit the load. In the reaction type overloads are obtained by passing high pressure steam into the low pressure stages, which is not economical.

In order to reduce some of these disadvantages, the Double Flow type of reaction turbine was introduced (Fig. 3). In this machine steam was introduced at the centre and flowed towards both ends, thus eliminating the dummy pistons, as the end thrust was balanced and the effect

thus neutralised. On the other hand, dividing the steam into two paths for the same volume, the blades required only to be half the length, which increases the inefficiency. This Double Flow type therefore finds its best market for use with low pressure steam, when the volume of the steam becomes large enough for the use of long blades.

Disc and Drum Turbines.

These are combined machines using a velocity element which replaces the high pressure portion of the reaction machine (Fig. 3). They are made both single and double flow and have many advantages compared with the straight reaction type, which are as follows :—

In addition to the usual throttle governing, the use of nozzles in connection with the velocity element allows cutting in or out of nozzles to suit the load.

Due to the considerable fall of pressure and temperature in the nozzles, the turbine cylinder has to withstand a very much reduced risk of distortion, and this feature also allows the use of a higher degree of superheat.

The efficiency of the turbine is much improved, as the greatest loss in the reaction type is in the high pressure part due to the short blades and the proportionate large leakage paths.

The length of the spindle is much reduced.

So important are these advantages that practically all the British and Continental makers of the straight reaction machines, including Messrs. Parsons, have made the change.

Impulse Turbines.

Though the disc and drum machines are a distinct improvement over the straight reaction type, still some disadvantages remain, which are eliminated altogether in the impulse type (Fig. 4).

The impulse principle, as before mentioned, may be used in two ways, namely, by compounding by velocity and compounding by pressure. Some makers use one method, some the other, and some both. The last appears the best, as compounding by velocity can be used with advantage in the high pressure portion, especially where superheat is used on account of the dryness of the steam. In the succeeding stage, however, the steam becomes wetter and the frictional losses increase at the high velocities used, thus compounding by pressure is more advisable in the lower stages.

Steam Turbine Speeds.

The efficiency of the turbine increases with the speed, and many

advantages are obtained by running them as fast as the generators to which they are attached will permit.

By building alternating current generators with smooth cylindrical fields, the evolution of high-speed turbines has been rapid, though some makers still stick to the salient pole type, which type cannot well be built to withstand high speeds.

With direct current generators, centrifugal stresses are reduced by building the armatures smaller in diameter and of greater length. One difficulty, namely, that of collecting the current from a fast revolving commutator is overcome by the use of a radial faced commutator, which avoids entirely troubles due to cross axial vibration.

In addition to high speeds reducing the cost of turbines, the weight and floor space are reduced, the factor of safety is increased, as joints are avoided and flaws in the materials are more easily detected than in any construction requiring large castings or forgings ; further, the peripheral speed is not increased and the centrifugal stresses are reduced.

As an example, to show the saving that can be effected in a 1,000 K.W. turbine at 1,800 R.P.M., the length between bearings was 12 ft. 7½ in., weight 7,000 lbs., maximum drum diameter 37¼ in., and the number of rows of blading 82. These dimensions for a 1,000 K.W. machine were, running at 3,600 R.P.M., respectively 8 ft. 8 in., 2,000 lbs. 20 in., and 49 rows of blades. The efficiency of the higher speed machine was 4½ per cent. better than the lower speed.

Effects of Pressure, Vacuum and Superheat.

While advantage in steam economy results from increasing the pressure, vacuum and superheat, care must be taken that these are not increased above a point where the advantage is obtained at too great an expense.

The temperature entropy diagram (Fig. 5) shows diagrammatically the heat content of steam between various limits and illustrates in a simple manner the energy available. The increase of entropy between two temperatures equals the summation of all the quotients arising by dividing each small quantity of heat added by the absolute temperature at which it is added. Thus, if equal quantities of heat are added, while the values of the temperature increase, the quotients are not equal, but are constantly decreasing. Entropy is approximately equal to the quantity of heat added, divided by the mean absolute temperature. To construct this diagram, from the properties of saturated steam tables, the line showing the heat added is taken, then the heat of vaporisation is drawn, this being horizontal, as no increase in temperature takes place, adiabatic expansion takes place, without receiving or giving up heat, and the diagram is then completed by the heat exhausting at constant temperature.

The diagram shows very forcibly that as the pressures increase the energy increase gets smaller and, consequently, as higher pressures need more expensive boilers and pipings, about 160 to 180 lbs., according to size of plant, is probably as high as the economy of steam warrants.

Similarly with superheat, as above, about 150 degrees superheat, the economy in steam is neutralised by the increased cost and maintenance of the superheaters, etc. (Fig. 6).

From a paper by Mr. E. Dreyfus I show an interesting curve, which illustrates the above, and also one showing the relative value of different vacua (Fig. 7).

Exhaust Steam Turbines.

The high efficiency with which the turbine works on low pressures has opened up an immense field, and wherever additional power is required this method of dealing with it claims very serious consideration.

For low pressure work the same objections do not apply to the reaction type, particularly the double flow, as do in high pressure work, as the volume of steam to be dealt with being so much greater the blades can be made of reasonable proportions.

The following are the conditions usually met with :—

(1) A constant supply of exhaust steam from either condensing or noncondensing engines.

This condition may be met by the pure exhaust turbine, steam being admitted about atmospheric pressure and expanded to vacuum. It may be provided with an auxiliary reducing valve to enable high pressure steam reduced to exhaust pressure to be utilized should the steam consumption of the engine be reduced or stopped for any reason. This reducing valve addition is not intended for frequent use, if such were demanded a mixed pressure turbine would be more suitable, but where the supply is sufficient and continuous the pure exhaust machine is more desirable, being more efficient than a mixed pressure machine.

The amount of steam required per kilowatt hour in an exhaust turbine is from 35 to 40 lbs. of steam at atmospheric pressure and exhausting into 28″ vacuum. Assuming then a noncondensing engine taking 40 lbs. of steam per K.W. hour, it is obvious that the output of the plant could be doubled by the addition of an exhaust turbine and condenser without increasing the boiler plant or fuel bill or any other expenses than the capital charges and a little extra labour, or, in other words, the cost of the K.W. hour would be nearly halved.

In the case of condensing engines, even though fairly efficient, a large increase of power and diminished rate of steam consumption can be shown.

Assuming a reciprocating engine developing 1,000 K.W. condensing and consuming twenty pounds of steam per K.W. hour, the steam available will then be twenty thousand pounds per hour, which would develop in an exhaust steam turbine a further 500 K.W. For the same steam consumption and with the same cut off, the output of the engine would be reduced, say, twenty per cent. under these conditions, so the total output from engine and turbine would be 1,300 K.W. for twenty thousand pounds of steam, or 15.4 pounds of steam per K.W. hour, as against twenty pounds with the engine alone, and with the same coal consumption an increase of thirty per cent. in output.

If it be possible by increasing the cut off to maintain the full output of the engine, one would get, say, 1,000 K.W. at twenty-five pounds per K.W. hour from the engine, and from the turbine 625 K.W., or a total output of 1,625 K.W. for twenty-five thousand pounds of steam, which again gives you 15.4 pounds of steam per K.W. hour.

A fairly efficient reciprocator has been assumed in the example given. It will be obvious that the less efficient the engine the greater will be the demonstratable advantage of laying down exhaust-steam turbines to work in conjunction with them.

(2) An intermittent supply of exhaust steam from various sources, such as winding engines, rolling mills, steam hammers, etc.

There are two ways of dealing with this, the first is by using a pure exhaust turbine, in the cases where the period when no exhaust steam is available is short, together with a heat accumulator. This is installed between the engine and the turbine and consists of a large reservoir of water, the exhaust steam is passed through this, which heats the water to saturation temperature ; some is condensed, and the rest passes on to the turbine. When the exhaust supply ceases the pressure in the accumulator falls slightly and a certain amount of water boils off and keeps the turbine running until the engine again exhausts into the reservoir. When the period of cessation of supply of exhaust steam is, say, longer than two minutes this system will not do and instead of it a mixed pressure turbine would be recommended.

A mixed pressure turbine (Fig. 4) is similar to a high pressure turbine, but has an additional inlet to introduce steam at about atmospheric pressure, which steam combines with that already expanded to atmosphere, the whole undergoing further expansion to vacuum. By the use of an automatic governor, whenever the supply of exhaust steam is insufficient to maintain the output of the machine the governor automatically operates the high pressure steam valve and admits the requisite amount of h.p. steam to the high pressure portion. This makes an extremely elastic machine and though not so efficient by about 5 per cent. as a pure exhaust turbine, is more commonly used.

(3) Instances where large quantities of low pressure steam are required for heating, boiling, etc., and high pressure steam for engine work.

Large hospitals, chemical works, sugar factories, breweries, and similar places frequently require steam at two pressures, and the lower pressure is generally supplied through a reducing valve. Instead of a reducing valve a back pressure turbine may be installed. This uses high pressure steam only and exhausts against a back pressure varying from atmosphere to 70 lbs. gauge, according to the purpose for which the steam is used after it leaves the turbine, or a reducing turbine may be used in which one part of the h.p. steam, after going through the high pressure portion of the turbine and then is used for heating purposes, and the remainder of the h.p. steam is utilized in the low pressure part of the turbine.

In conclusion, though I have not touched on a vast number of interesting points in steam turbine work, I trust that the information given may prove of benefit to the members.

[For diagrams see end of book. The Author also illustrated his paper with a number of lantern slides.]

Discussion.

Mr. E. S. Hume said: I was very much interested and pleased with Mr. Gardam's paper, and am sure it will prove of great value and use to the members of the Institution. In connection therewith, as usual, I look to the practical side of the paper in order to see what economies are introduced or advantage in the way of labor saving which can be effected by the study of such a paper. I noticed that Mr. Gardam refers to the turbine being used for driving compressors. By the word compressor I understand the author refers to air compressors, and I would be pleased to get further information on that subject from the author concerning the power of a turbine which would be capable of compressing 800 cub. ft. of free air per minute to a pressure of 100 lbs. to the square inch, and also the approximate cost of such a turbine and air compressor complete, and the space it would take up compared with an engine of ordinary reciprocating type and compressor of usual type, such as made by the Ingersoll-Rand Co. Then in connection with the mixed pressure turbine referred to by the author, I would be obliged if he would give the following information, viz. :—

1. The most suitable and economical position for a condenser;
2. Should it be put in alongside the turbine? or
3. Is it more economical to put the turbine on a stand and the condenser underneath it? or

4. Excavate for the condenser and place the turbine and generator on girders across such excavation ? and

5. What, from the author's experience of these mixed pressure plants, is the most economical in first cost and maintenance of these three different methods ? also

6. What should be the temperature of the condenser water and the volume of water required to secure the 28.5 inches of vacuum referred to by Mr. Gardam in a mixed pressure turbine of, say, 500 K.W. alternating type, 200 volts, 50 cycles, where exhaust steam available is from other engines in the same power house with a consumption of 10,000 lbs. per hour on an average ?

Mr. H. Broadbent said : The author has left little room for discussion on his paper, as he has kept so close to the generally accepted statements as to what turbines could do and are doing. I would like to have heard that in the smaller sizes greater economy had been obtained, but it appeared that up to sizes capable of driving a 1,000 K.W. generator the reciprocating engine is still as economical. Unfortunately, there appeared to be no immediate prospect of units of a large size being used in this State for any purpose, so that it is no use coveting the undoubted efficiencies of large turbines. A very few years ago makers of direct current generators fought very shy of the quick rotating turbine, but, of course, the inevitable had to be faced, and now makers have nearly overcome all their initial troubles, which will be greatly welcomed in those centres where "continuous current" is desirable. As we can find no work for the larger sizes of turbines and the smaller ones show us no advantage in running costs, we can only look to the exhaust or mixed pressure turbine as being likely to be of much use in this State. The figures quoted, although on first acquaintance they read more like fairy stories, are no doubt obtainable under the conditions laid down. The author points out the conditions usually to be met with where an exhaust turbine could be economically installed, and I have no doubt that on several of the large mines on the goldfields they could profitably be erected if the condensing arrangements were suitable. Naturally, no fixed rule could apply for the adoption of these turbines ; for instance, in the works with which I am connected the consumption of fuel amounts to about 12,000 tons per annum, but by no feasible combination of reciprocating and exhaust turbines could one-third of that fuel be saved. An ordinary electricity supply station with a load factor of about 20 per cent. and a very fluctuating output would have to adopt a very complicated combination to derive any appreciable benefit. Either a separate turbine would have to be attached to each engine, or a larger turbine common to a group of generators ; in either case one generator would be capable for a good many hours of the day to cope with the load

without the assistance of the turbine, consequently the load being divided between the two, neither would be working economically, and more attention would be required than in the case of only one unit at work. In the case of grouping to one turbine, the advantage of having absolutely independent units would be lost. No doubt for a certain portion of the day or evening it would be possible to show an economy, but in a case like the one I have in mind I am afraid that the extra trouble and complications would counterbalance the saving in fuel effected. There is no doubt the turbine will be the large prime mover for many years to come, and I should have been pleased if the author had given us one or two examples of the very large installations now at work and if possible their economy under actual working conditions. The author stated that the maintenance of turbines is small: I should like to know if he can amplify that, and if possible give us an idea of the state of the blades of a large turbine after years of running, and if the efficiency drops till renewal of blades is necessary.

Mr. G. H. Randell said: In setting out the difference between the pressure and impulse types of turbine Mr. Gardam says: "In the reaction type the nozzle and wheel are one, the wheel moving in the opposite direction to the steam with the same velocity, and the whole pressure drop taking place in the wheel itself." Now in the pressure type, partial expansion takes place in the guide vanes, thus giving the steam increased velocity, and the energy of the steam impinging on the moving vanes is therefore partly kinetic. This kinetic energy is given up to the moving vanes and thus the pressure type works partly by impulse, and I maintain that there is no hard and fast difference between the two. I do not see how in the pressure type the nozzle and wheel are one, or that the steam flows at the same velocity as and in the opposite direction to the moving blades, that is at an angle of 180 degrees. Regarding the "temperature entropy" diagram which the author showed us for illustrating the available energy of steam in the lower stages, although this illustrates the idea very clearly to those who have a clear perception of entropy, I think in a mixed institution like ours, where some of us are not experts in "Thermo Dynamics," a further explanation might have been helpful. Now the work done by a gas in expanding is equal to the pressure multiplied by the increase in volume. Taking one lb. of steam at 120 lbs. pressure per square inch (abs.), let it be expanded down to 60 lbs. per square inch. Assuming that the steam in expanding obeys "Boyle's Law" (which it does near enough for our purpose), the volume will be doubled in expanding from 120 lbs. to 60 lbs. Also in expanding from 120 lbs. (abs.) down to .937 lbs., absolute. We have the following expansions:—Above atmosphere: 120 lbs. to 60, 60 lbs. to 30, 30 lbs. to 15; below atmosphere: 15 lbs. to 7.5, 7.5 lbs. to 3.75, 3.75 lbs. to 1.875, 1.875 lbs. to .937. All these energy steps are equal, so we see that from 120 lbs. down to atmosphere we have there

expansions, and from atmosphere down to approximately 28″ of vacuum we have four expansions. From this we see that with an initial pressure of 120 lbs. there is more energy in the steam in the lower than in the higher range, working to 28″ of vacuum. However, a large percentage of the available energy in the lower range is lost by condensation of the steam. I do not think the author's explanation of the water accumulator used in connection with exhaust turbines quite clear. He says "The exhaust steam from the supply is passed through water, heating the water to 'saturation temperature.'" I do not realize the meaning of "saturation temperature" of water. Now the steam passing through the water first condenses, giving up its sensible and latent heat until the water is raised to the temperature of the steam, then the steam passes on through the water at its saturation temperature for the pressure then existing in the system, and the water and steam remain in a state of equilibrium. Now if the supply of exhaust steam fails, the pressure throughout the system falls and for this lower pressure the steam and water are in a condition of superheat and ebullition occurs supplying the turbine with steam at a reduced pressure. In concluding these remarks, I wish to express my appreciation of Mr. Gardam's paper, which I think contained much useful information.

Mr. J. R. W. Gardam, in reply to Mr. Hume, said that it may be of interest to members to explain that the suitability of the steam turbine for driving air compressors and blowers is due to the very high angular velocities obtainable, without which the principal of centrifugal water pumps for use with gases was not possible owing to the difference in densities between a fluid and a gas and to the latter being compressible The lower the density of the gas the higher will be the speed necessary to obtain equivalent pressure. Though many sizes of turbo compressors and blowers have been built under Prof. Rateau's patents, the full range of sizes has not been fully developed, and on communicating with the works I was informed that one of so small a size as Mr. Hume asks particulars for has not yet been built, and, consequently, I regret not being able to give the information desired. With regard to the best position for a condenser attached to a steam turbine, due to difficulty of preventing air leaking into a high vacuum, it is always advisable to reduce to the utmost degree the length of connection between the exhaust outlet and the condenser. It has consequently become absolutely general practice to suspend the condenser from the exhaust outlet, which in addition ensures the best drainage. I would in the case suggested strongly advocate excavating a pit for the condenser and erect the turbine on girders at floor level. As to the temperature and volume of the circulating water to produce 28.5″ vacuum, these are dependent on the inlet and outlet temperatures and are approximately as follows:—Since each pound of water will extract one B.Th.U. and as the temperature of steam at that degree of vacuum is 90.24 degrees, the heat to be got rid of is

the total heat of steam, viz., 1,178 less 90.24, say 1,088 B.Th.U. Assuming the inlet water is 60 degrees Fah., then 30 degrees may be added to it, and consequently 36 lbs. of water per lb. of steam will be required, or a total 36,000 gallons per hour. If the inlet water is 70 degrees, then 54,000 gallons will be required. To obtain a 28″ vacuum the quantities would be 27,000 and 36,000 gallons with inlet water at 60 degrees and 70 degrees, respectively. In reply to Mr. Broadbent, I do not agree with his view regarding the future of turbines in this State, that there is no work for large sizes, and no use for small ones. I think even down to very small sizes that the other advantages in using turbines are of real importance, even if no saving in fuel and water is obtained, including reliability, maintenance, attendance, saving in space, increased output, etc. The efficiency of the turbine is unaltered after years of operation, while we know how this falls off in reciprocators, and as regards reliability, I have records of turbines running continuously without a stop or adjustment for 14 months, which, while not desirable, could not be done with a reciprocator, owing to the attention the valve gear, piston rings, piston and valve rod packings, etc., require. Regarding the maintenance of turbines, there are no rubbing parts save the main bearings, which, being water-cooled and not subject to reversal shocks, have a considerable life. The blades are not affected by long service, unless the feed water contains active chemicals in which case erosion may occur. I have seen turbines opened up after many years' operation showing absolutely no wear. In reply to Mr. Randell, the difference between the impulse and reaction principle is quite marked, though one is liable to be misled by considering that the Parsons machine operates on both principles. In reality, however, the velocity imparted to the steam is little more than sufficient to enable the steam to enter the moving blades without shock. The best analogy by which to explain the two principles is a falling ball. In falling it loses potential and gains kinetic energy and strikes the floor with an impulse which deforms the ball and floor, and being elastic they endeavour to regain their normal shapes, which forces the ball up by reaction. The speed of an impulse wheel must be half the speed of the steam, in order to use all the velocity in the steam, as the steam must rebound from the blades at the same speed as the blades are travelling at. The wheel must travel in the same direction as the steam. In the case of the reaction type in order to utilize all the velocity in the steam the blades must move backwards with the same velocity the steam is travelling at.

TIMBER ROAD BRIDGES.

(By J. E. G. Turnbull.)

In the history of civilization various periods have been distinguished by specific titles such as the stone age, the bronze age, and the iron age. Similarly the history of bridge construction may be divided into the stone age, the timber age, the iron and steel age, and, lastly, the reinforced concrete age. In our State of Western Australia the " stone age " of bridge construction has scarcely dawned, or at any rate has not developed beyond an early-morning stage, for to the best of my knowledge there is no example of a brick or masonry arch-road bridge in the State. So, too, the progress of iron and steel bridge construction has not proceeded very rapidly nor to a marked extent ; the few steel road bridges that do exist are railway overbridges, the largest of which are those at Beaufort Street and William Street, (and we are hoping soon to see another at Melbourne Road).

Although reinforced concrete has begun to be used to a considerable extent for buildings, and in some departments of engineering construction, it has not yet been employed in a road bridge in Western Australia ; so that for all practical purposes we may be said to be still in the timber age of bridge construction.

This is, no doubt, the inevitable consequence of the distribution of the natural resources of the country. Our building stones are either too expensive to obtain and work, or are deficient in quality ; local bricks have not been of that uniformly high character as regards hardness and durability requisite to induce engineers to use them with confidence in such important works as arched bridges. Iron and steel have to be imported at great cost and delay, and no natural cements have yet been discovered. Whereas our local timbers are of the highest quality in respect to both durability and strength, the supply is well-nigh inexhaustible, their cost is, or at any rate has been till quite recently, very moderate, and the skilled labour required for their manipulation has been more readily obtainable than for other materials of construction. Hence it follows that when one proposes to deal with road bridges as they exist in Western Australia the field is practically restricted to those built of timber.

The first timber bridge no doubt was created when some Darwinian ancestor of ours found a prostrate monarch of the forest fallen conveniently across a gorge or stream, which he wished to cross, and he gratefully took passage thereby.

Primitive man took a lesson from similar accidents and made his first essay in bridge building by felling a tree so as to lie across the stream

to be crossed, amplifying the construction later on by the addition of a second tree parallel to the first, with perhaps a third and fourth, according to the width of roadway required. Saplings or branches laid transversely upon these to form a deck or rough roadway would be the next development. To make the going surer for horses and smoother for wheeled vehicles a layer of earth or gravel would be placed on top of the corduroy deck, and a very serviceable bridge would result. Such types of bridge may still be seen in the country districts, where economy is the prime consideration, though a kerb or gravel log and a rough handrail are generally added. The defects of this type of bridge are a roughness of appearance, which, though at first perhaps not unpleasing from its air of rugged simplicity, may soon deteriorate into unkemptness and disruption unless a considerable amount of labour and care is expended upon all joints and scarfs ; and secondly, the earth covering of the floor by retaining moisture promotes decay and further prevents the progress of the decay being noticed until perhaps an accident results from collapse of some part of the flooring, when it becomes necessary to remove the gravel to allow of repairs being carried out.

If a deck of sawn or hewn planks be substituted for the saplings the bridge will be greatly improved and the need for the gravel top is not so apparent.

Bridges with such superstructure have been constructed by our own Public Works Department where suitable timber has been plentiful in the locality. The considerations which decide whether such round logs shall be employed in preference to sawn beams are the occurrence of suitable trees near the site and the cost of preparing them, as against the expense of purchasing and transporting sawn beams from a distant mill. As in all engineering construction, it resolves itself into a question of achieving the desired end at the lowest ultimate cost. If necessary to study appearance, the round logs may be hewn square, though it seems hardly worth while to put in this additional labour for so little advantage, particularly as this squaring somewhat reduces the strength of the beams.

So far only the superstructure has been mentioned, but the single-span bridge soon reaches its limit and the majority of gullies and streams require several spans, and the question of substructure has then to be considered.

The piers which constitute the substructure may be built of masonry, and we have examples of such, though more generally the use of masonry has been confined to the abutments, as in the case of the Fremantle road bridge over the Swan River. The piers usually consist of piles driven into the ground, connected together at the top by caps (single or halved) on which rest the corbels or beams. Where there is sufficient

depth of compact soil the piles are driven till they satisfy a test, which takes the form such as "for the last foot of driving the piles shall not sink more than, say, $\frac{1}{4}$ inch for each blow of a 20 cwt. ram falling 8 feet." The exact terms of the test will vary with the judgment of the engineer, but a minimum depth of driving should be specified. If there is a rocky substratum it will be sufficient to drive thereto, provided the surface soil is deep enough to give adequate support to the piles. If the surface soil is shallow, or there is liability to scour, it may be necessary to blast the rock and drive or plant the piles, as may best suit the conditions.

When the rock is on or close to the surface it is usually found most satisfactory to place the piles on a sill, which may be secured by lewis or cranked bolts either to the rock itself or to a concrete footing built upon the rock.

The number of piles to a pier depends, of course, upon the width of the bridge and the loads to be carried, and to some extent upon the height of the pier. In the standard design of the Public Works Department of Western Australia there are three piles to a pier for bridges up to 16 feet wide.

Up to a height of 17 feet of pier the piles are driven vertically, but above that height the outer piles are driven to a batter to give greater lateral stability by increasing the spread at the base.

Up to a height of 8 feet no bracing is necessary. Above this height braces are provided. As braces to be effective should not be at a steeper angle than 60° to the horizontal, it follows that when the pier reaches a height of a little more than the width of the bridge a single brace becomes too steep for efficiency, and, incidentally, too long for easy handling. Then the pier is divided, as it were, into stories by horizontal walings and each storey has its own diagonal bracing. Theoretically a single brace would be sufficient and the double cross-bracing usually employed is strictly speaking redundant, but as the single brace, to be equally effective in preventing rocking in either direction, should be capable of taking up compressive or tensile stresses indifferently, and as the simple bolting does not furnish a perfectly satisfactory tension joint, the counter-brace is advisable to ensure the stress on the bracing being always compressive.

The section of braces and walings is a matter of judgment and experience, rather than exact calculation, but they should be in some kind of proportion to their length. In practice the sizes used are generally amply strong and quite a small brace will effectively stiffen a large pier, providing the fastening is well done. The brace should be brought into close contact with the pile by flattening the pile where necessary, or, rather better, by cutting a notch into which the brace fits well. A further refinement is to have a cog cut on the pile with a notch in the brace.

It is doubtful whether the gain in efficiency is commensurate with the extra trouble and cost involved. If the cogging were perfectly fitted, and always remained so, this practice might be worth while, but as shrinkage and consequent looseness of fit always takes place, the work must eventually be taken up largely by the bolts and the extra labour is wasted or partly so. The braces ought to have a good bearing against the caps and walings; in some old bridges the brace ends were notched into the walings, but not so much attention is paid to this point nowadays. With silled piers rather more care and attention should be devoted to the bracing, as the tenoned piles not being supported like driven piles by the surrounding earth, there will be more tendency to lateral swaying. Where the bridge is over a permanent stream it is not usual to carry the bracing below summer water level; and in our rivers this would not leave a great height unbraced. Extra lateral stiffness and stability may be secured by driving stay piles and connecting them with the main piles of the pier by walings and braces. Sometimes a single stay pile on the downstream side has been used as a buttress against flood pressures, but the Public Works Department standard design provides stay piles on both sides for tall piers.

When driven, the capping of the piles completes the pier. This is usually effected nowadays by double half-caps resting on shoulders cut on the pile-heads and secured by bolts passing through the piles. The former practice was to have a solid cap morticed over tenons cut on the tops of the piles and secured by hardwood pins or trenails, or sometimes wrot iron straps. The modern method has the advantage that the smaller timber of the halfcap is cheaper; it is lighter and therefore more easily handled; with the same amount of timber a longer and more stable bearing for the corbels or beams is provided by halfcaps than caps. The slighter timber of the halfcap is more flexible and can therefore be more readily adjusted in case of imperfect alignment of the piles. On the other hand, the cap has a better bearing on the pile, and no doubt the old-fashioned bridge builder would prefer wooden pins to iron bolts. Though the half-cap is the fashion here, the solid cap has plenty of friends, and there are undoubtedly points in favour of each method, and perhaps some members of wider experience and maturer judgment than the present writer may be able to determine the balance of advantages satisfactorily. The piers of the substructure being completed, the superstructure has then to be emplaced and the essentials are a deck of planks and longitudinal beams or stringers to carry it.

There may or may not be corbels under the beams at their bearing. With solid caps it was the practice to omit the corbel and lap-joint or scarf the beams over the piers, the present general method is to provide corbels and butt-joint the beams upon them. The use of the corbel allows of regular spacing and perfect alignment of the beams, and gives a stiffer joint than the scarf with less labour. There is one point regarding

corbels which should be mentioned, and that is the ambiguity which they may introduce into calculations. Given the span of a beam and the load upon it, any engineering pupil can compute the bending moment, and, the working stress being determined upon, he can compute the factor of safety of an existing beam or the section of new beam required. When there is no corbel he may take the clear span between caps as the basis of his calculations, or, to "make assurance doubly sure," the distance between centres of piers. But when the corbel is introduced what dimension shall he adopt as the span of his beam? No authority will allow him to take the clear opening between the corbels and in the absence of a definite rule he usually falls back on the span between centres again. So that for a given load he will derive the same section for the beam, whether a corbel be used or not, which certainly does not seem quite logical. There cannot be any safer way of determining the case of the beam without corbel than that suggested, and as the corbel must surely stiffen the beam there ought to be some allowance made for it in deciding the section. The problem does not seem to admit of any exact solution and the corbels are frequently regarded merely as joint plates, which view errs, if at all, on the side of safety. The Public Works Department standard design recognises the stiffening effect of the corbel by making the end spans two feet less than the main spans, the corbels being omitted on abutment piers. If the corbel be regarded merely as a fish plate it might with economy be made somewhat shallower than is usually the case, *i.e.*, of similar depth to the beam it supports. In any individual case a few trials could soon determine the most economical length of span, having regard to the relative costs of piers and beams; for P.W.D. bridges the standard has been fixed at 20 feet, which is about the limit for beams of moderate size, and was determined as the result of many years of experience with various spans.

For long spans shallow beams may be used with under-struts to stiffen them. To be permanently effective, this arrangement ought to be made so as to be adjustable after shrinkage, but as this would introduce some complication (of wedges, etc.) it is not usually done, and after a time distortion will take place unless the maintenance be very thorough, which it usually is not.

If seasoned timber be used for such strutted work there can be no objection to its employment, provided the joints are well designed and properly fitted.

The old road bridge over the Swan River, at Fremantle, was the most striking local example of this type of construction, and it did good service for about thirty years. Built in the '60's, when appliances and plant were not so easily procurable as now, and before the advent of railways, the builders could not readily obtain nor drive very long piles. But the piers had to be high to give headroom for the river traffic, so

they were built up in two stages, the cap of the first or driven piles forming the sill for the piles of the next stage. The majority of the spans were about 25 feet and the deck beams were stiffened by under-struts, wihch also served, aided by longitudinal ties, to brace the piers, these being also elaborately braced laterally. The two navigation openings were about 47 feet span and the arrangement of truss and under-strutting adopted was extremely complicated, and it would be a good exercise for students to compute the stresses on the various struts, beams and ties of this design.

In spite of its imperfections this bridge had an honourable career and the greater part of the substructure still exists and continues, in spite of some deformities, to carry the tramway to North Fremantle. Much of it is, however, shortly to be removed and replaced by new piers.

The strutted beams were repeated in the later work in this bridge (and its extension) in order to use as much as possible of the old structure and to retain uniformity, but it is more usual in long spans to adopt a framed girder or truss.

The understrut can have only a very limited application, for with spans of great length the struts would require to be so long and of so large section that an intermediate pier with smaller beams would be more economical. Other objections to understruts are that they are liable to damage by floating logs during floods and by boats where over a channel, and they may be inconvenient because of the reduction of headroom they cause.

Most of our bridges which cross a navigable channel have a truss span of 40 feet or thereabouts, the truss adopted being of the form sometimes known as the " New Zealand " truss, and introduced into use here by the late Mr. C. Y. O'Connor when Engineer-in-Chief for this State. In such a truss the diagonal members are all in compression, and the vertical tension members being formed of iron rods, the only tension member of timber is the lower chord or boom. In the central panels counterbraces are inserted to take up the stress when any distribution of the loading should cause a tendency for the main diagonals to come into tension. The composite nature of this truss permits of adjustment by screwing up the tension rods or bolts from time to time, as shrinkage and vibration render it necessary.

The cross-girders that carry the stringers on which the decking is laid are slung below by the vertical tension bolts. This seems on the whole a more desirable arrangement than to have them resting upon the lower chord, although it might be argued that it makes the safety of the bridge too entirely dependent upon the tension rods

In this method we increase the minimum headroom by the depth of the lower boom, and between the cross-girders we get the benefit of increased headroom to the amount of their height. Further, with the girders above the boom the joints would be complicated by their occurrence at the panel points, also in the event of a cross-girder requiring renewal the replacement can be effected more readily and quickly in the underslung arrangement, as it can be done from below without stripping the deck.

The size of the cross-girders might be reduced by placing them above the lower chord and spacing them more closely so that the stringers could be dispensed with. It would then be necessary to have longitudinal or diagonal decking spiked directly to the cross-girders. This arrangement is sometimes adopted, though I am not aware of an example in Western Australia and think the usual method the better.

The joints of the truss require particular care in design and the thrust blocks should be of well-selected hard and straight-grained timber. At the end of the lower chord sufficient timber must be left beyond the foot of the end diagonal to prevent detrusion or shearing along the grain.

The truss is screwed up so as to have an initial camber for the sake of appearance and to prevent any sagging when the load is put on. Lateral struts are fixed from the ends of the cross-girders to the top boom to keep the truss upright. When the span is so long that the lower boom would be inconveniently large if in one stick, it may be built up of two, or more, smaller sections. In such case the pieces must be bolted or clamped together to ensure their acting as one piece. The bolt holes are not desirable, as they weaken the boom by reducing its cross-sectional area, and on that account clamps are preferable.

The remaining detail of construction which I will mention is the wind bracing, which is fixed diagonally below the stringers to prevent lateral bending.

There are numerous other varieties of timber trusses, all, no doubt, having their good points, but the general principles are the same, and I have confined myself to the type used here.

The deck planking is usually 3 in. in thickness, and though this is in most cases rather stronger in proportion than the beams, it is not advisable to use thinner decking on account of wear and tear, and because of the tendency of slighter planks to curl up. The deck should be well spiked to the beams, though the tendency has been to rather overdo this work, as may be gathered by examination of bridges from below and noting how badly the beams are split in many cases by the large deck spikes used. The narrower the beam the worse the case, and on this account the width of beam ought not be less than 6 in., and in any

case the holes for spikes should be bored. For 3 in. deck 6 in. spikes are long enough.

The question of covering the planks with metal is debatable. If asphalt were used the wear on planks would be saved and not much extra weight would be put on, and moisture would be excluded.

Throughout the construction, wherever possible, provision is made for shrinkage, so that timbers shall not be hanging on the bolts instead of resting on their proper bearings. To this end the holes through the half-caps and through the outer beams and corbels for the bolts which secure them to the piles are slotted vertically, and the pile heads are cut off an inch below the tops of half-caps to prevent riding of the corbels on the tops of piles when the half-caps shrink.

The ends of the approach banks, unless the abutment be of stone, are generally retained by horizontal sheeting spiked to the backs of the piles of the abutment piers and wings. In some cases the toe of the bank is allowed to run out beyond the abutment and it is then protected, if not of rocky material, by stone pitching.

The width of a bridge will vary with the importance of the road, and the amount of traffic upon it. The minimum width of clear roadway provided by the Public Works Department standards is 12 ft., and this is only used on the less important country roads, 14 feet being more usual, 16 feet, 20 feet or even 24 feet being adopted in busy localities. In the narrowest bridges vehicles cannot pass one another and in the earlier years of the history of Western Australia all the bridges were narrow, from financial reasons. When the bridge was of considerable length it was customary to provide an increased width over a couple of spans, about midway in the length, to form a "turn-out" or "lay-by," On the old bridge over the Lower Canning, (which was removed about three years ago) by some oversight the necessary turnout was not provided, although the roadway was too narrow (12ft. between handrails) for vehicles to pass one another. From each end up towards the centre there was a grade of about 1 in 10, so that it was not possible to see from one end to the other. To make matters worse, the approaches curved away in opposite directions at either end. The consequence was that it was quite possible for two drivers to come on to the bridge from opposite ends and not be aware of one another's proximity until they almost met at the top. I have seen this happen more than once, together with the foregone conclusion, which was that after argument, and language, one driver had to back his horse the whole way down the steep grade and off the bridge—a very awkward and possibly dangerous proceeding. In the new bridge which replaced this structure the roadway has been made wide enough (16 feet clear) to prevent such happenings in the future and the grades have been flattened considerably (1 in 25).

A grade, unless of the flattest, is not desirable in a bridge, but several of the road bridges of W.A. have been built with a "hump," as the above-mentioned Canning Bridge and Perth Causeway. When one considers the low shores at these sites and the high approaches and extra height of piers that would be necessary to keep the whole bridge at the same level, even with the very moderate headroom provided, the conclusion is forced that the designers did the best possible under the circumstances, however much they may have recognised the desirability of dispensing with the ungraceful and inconvenient hump.

There are many points which have not been touched upon, and I will briefly mention those I am most conscious of:—The provision of a hand-railing and the necessity for making the lower portion sheep and baby-proof; the kerb to keep the wheels of vehicles from colliding with the hand-railing; "escapes" for the security of foot passengers; the need for keeping the deck level well above flood water-mark; the consideration of the possible effect of the bridge and its approaches in banking up the flood waters above it and the necessary area of waterway to be provided to avoid this.

In conclusion, I would say that timber bridges have done yeoman service in this State and no doubt will continue to furnish the bulk of bridge construction for years to come. Unfortunately, they are not of long life and no matter how well designed will not furnish a lasting monument to the skill of the builders. Their cheapness is their recommendation, but if the cost of large timbers continues to increase as it has done of late, it is quite on the cards that before long it may not be economical construction to use timber for important bridges, and more durable materials will be sought. In such case our engineers will have a chance to display their skill in the design and construction of steel bridges, and also probably in the use of reinforced concrete work, which, from the engineering standpoint, is, I think, a "consummation devoutly to be wished."

Discussion.

Mr. J. F. Ramsbotham said:—The whole question of timber bridges and wharves is to the engineer from the "Old Country" an exceedingly interesting one, and, given money, an engineer can accomplish any engineering gymnastics. I have some doubts about the wisdom of using jarrah without heart in preference to jarrah with heart—not on the score of strength, but on the grounds of cost. For the undertaking I am at present engaged on the timber being admittedly used only for temporary work, to have used jarrah with heart would have made a difference of £4,055, being about an addition of 25 per cent. Further than that my practical carpenters tell me that hewn jarrah is considerably stronger

than sawn jarrah, as the hewers must hew with the grain. Again, further than that, the heart, which is the weak part of the beam, occurs in the neutral axis, which is the best position possible from an engineering point of view. Then again, I notice that exception having been taken to the heart for a beam, no exception is taken to the heart in a pile which carries the beam: the conclusions do not strike one as logical, and perhaps the author can throw some light on the question and, further, if the author can give any data on the relative strengths of jarrah with and without heart, I am sure it will add to the value of his excellent paper.

DOCKS :
THEIR CONSTRUCTION AND DESTRUCTION.

(By Joshua Fielden Ramsbotham.)

It is with a certain amount of diffidence that the Author consented to write a paper for the Western Australian Institution of Engineers, as there is a danger of his being out of sympathy with the meeting—as in choosing the subject of his paper the Author has had to rely on work done in the "Old Country," at Liverpool.

The Port of Liverpool is essentially a modern port, and it is the product of the genius of man combating the forces of nature, and it may be mentioned that the fierce battle of "sea and sand" is still being waged night and day, year in, year out, and there is every probability of the fight going on *ad infinitum*.

The first dock was built in the year 1709, and in the days of sailing ships the bar, which it may be mentioned is eleven miles from the mouth of the river, was a nuisance, but not aggressive ; and accordingly the Port steadily grew in size, wealth and importance.

In 1890 the increased size of steamers, the finality of which has not yet been reached, focussed all eyes on the Port, and it was a case of "to be or not to be."

The Dock Board took the bull by the horns and had the first suction dredger in England equipped and commenced the fight under the guidance of their present Engineer-in-Chief, Mr. Anthony G. Lyster.

From 1890 to 1893 two small 500-ton hoppers had been extemporised, in 1893 a large suction dredger of 3,000 tons, the "Brancker," was specially built, in 1895 another similar dredger, viz., the "G. B. Crow," was built, and finally, in 1909, the "Leviathan," a dredger having a nett hopper capacity of 180,000 cubic feet and capable of loading herself with 10,000 tons of clean sand in fifty minutes, was brought into the combat.

In addition to this, training walls have had to be built to prevent erosion on the concave side of the channel. "Time," the factor in all engineering problems of this character, has yet to demonstrate the wisdom of this procedure, but the results so far have been a success.

Surely it is no small performance to have, since 1890, removed 161,072,620 tons of sand from the bar ; and whereas in 1890 there was only 10 feet of water on the bar, there is now maintained a depth of 30 feet 3 inches on L.W.O.S.T.

The unit of cost works out, including all working charges and a proportion for actual superintendence but no allowance for interest on capital cost or depreciation, as follows:—

Wages	.23	pence per ton
Supplies	.25	,, ,,
Repairs	.13	,, ,,
Total	0.61	,, ,,

If success had not been attained Liverpool could not possibly have kept her trade, which in 1908 amounted to 18,111,814 tons. Nothing succeeds like success, but those outside hardly realise the intense anxiety a bar of sand caused the members and engineers of the Mersey Docks and Harbour Board.

To my mind there are a few points of similarity between the River Mersey and the River Swan: both have a bottle neck at the mouth and broaden out in their upper reaches, but the River Swan, to my mind, is unique among both the natural and artificial harbours of the world in having no maintenance dredging to do, and the late Mr. C. Y. O'Connor will never have a more fitting memorial than the Fremantle Harbour.

In carrying out works there are certain incidents which stand out and photograph themselves on your mind with an indelible mark—perhaps the following may be of interest.

Whilst the author was constructing the Brunswick Dock Extension, Liverpool (lantern slides of which have been shown to you), it was necessary to re-shore a dam on to a new wall which had been previously built behind the old wall which took the shores of the dam, and then remove the old wall.

The dam in question was a single skin piled dam, driven on a rock bottom, with a quantity of clay tipped on the outside.

The shores were 10 feet centres apart in plan and so placed vertically that each shore had the same load on it. Having dried the dam and done all the necessary work behind, it was necessary to remove the wall, as mentioned above.

Under the most favourable circumstances this is a disagreeable job and consequently the work was delayed until the neap tides came on, which gave a less head of water on the dam and, of course, increased the factor of safety on the dam.

Small 4 oz. charges of cheddite were used and fired electrically, and during this operation a large granite stone accidentally went over the face of the wall and knocked a tier of shores out from top to bottom.

The author saw this happen and afterwards worked out the following figures for interest. The clear span of the walings was increased to 19 feet, each waling taking 19.8 tons. Now the breaking weight of a 14 in. x 14 in. waling for a clear span of 19 feet, with a uniform load, is 48.14 tons, therefore the actual factor of safety is

$$\frac{48.14}{19.8} - 2.42.$$

Although this extra load was thrown on the walings, there was no perceptible creeping of the dam, but if this work had been done on a spring tide the result would have been a disaster. In this class of work minimise your risks as much as is possible, and always try and see what contingencies may arise and accordingly provide for them beforehand.

The Brunswick Dock Extension, referred to above, was " Construction and Destruction " in its true sense, and the scheme was briefly as follows: the removal of the two Brunswick Graving Docks, the Union Dock with its two passages, and the constructing of new walls, new 100 foot passage with double track hydraulic swing bridge, sheds, railway sidings, etc.

The two graving docks were built in the year 1831 and were splendid examples of early dock engineering. The Union Dock was built in the year 1888 and the work was done in the early days of " concrete," and consequently the engineers, not knowing as much as is now known about concrete, had wisely erred on the safe side as regards the quantity of cement used.

To the author's mind, it is a debatable point on the policy to be adopted in dock and harbour construction whether your work has to be of such a character as to last for all time or to adopt the policy of " temporary " and renew your wharves every five or more years.

The policy of " permanency " has its drawbacks, and the recent increase in the size of vessels has made obsolete costly dock and harbour undertakings, and necessitated expensive enterprises wherever those vessels have gone, but it has been demonstrated that the paying boat is the large steamer, and it is only a question of time before " Mauretanias' " and " Lusitanias' " make Fremantle the first point of call on their voyage to Australia. " Time is money," and as Australia increases in wealth, business and importance, that fact will be realised, and public opinion, if nothing else, will demand a more rapid means of communication with the Old Country.

If the policy of " temporary " is adopted, trade must not be dislocated or hampered during renewals, as it has a disagreeable way of seeking " pastures new " and to overcome that dislocation your port must be larger than is necessary for present requirements, which means that some works are not remunerative.

This is a question that will have to be faced in the immediate future in Australasia, and without doubt it will be satisfactorily settled.

Now as regards "Destruction," the author purposes to describe one of the large submarine blasts, lantern slides of which have already been shown to the meeting.

Situated as we were, with valuable ships, property and human beings all round, the greatest care had to be exercised. When working in the dry, "time fuse" was first of all used, but owing to some "shots" doing more than was expected of them, and consequently the next shot having less to do, the result being that a fragment of masonry would fly and possibly do some damage to life and property. A good deal of experimental work having been done, electrical firing was adopted, and the author gives a few details as it may be of interest.

In the firing of 7,700 low tension detonators, only six miss-fires were detected, and at the very least a saving of 30 per cent. was effected in explosive used as compared with fuse firing.

Testing Detonators.

A large number of tests were carried out with both high and low tension detonators under working conditions. Possibly they may not suit a scientist, but being carried out under conditions similar to those encountered in actual working, they may possibly be a help to engineers working under similar conditions.

Test on "No. 6 Curtis and Harvey" Low Tension Detonators

The resistance of 600 feet of 7/16 S.W.G. cable .21 ohms.

" " 44 " 1/16 " " .10 "

The recorded volts and amperes required to explode 1 detonator, and from which the resistance has been calculated, are as follows :—

	Volts.	Amps.	Resistance by Calculation.
	.8	.3	2.66
	.75	.3	2.5
	.7	.35	2.0
	.74	.35	2.1
	.8	.4	2.0
	.81	.4	2.02
	4.60	2.10	13.28
Average ..	.76	.35	2.21

Total resistance of 250 detonators arranged in 10 groups of 21 and two groups of 20 detonators each :—

Resistance of 21 detonators in parallel $\frac{2.21}{21}$ =.10 ohms.

„ „ 44 feet of wire as above .. =.10 „

.20 „

„ „ 10 groups each having 21 detonators in parallel $\frac{.20}{10}$ =.02 „

21

„ „ 20 detonators in parallel $\frac{2.21}{20}$ =.11 „

„ „ 44 feet of wire as above .... .10 „

.21 ohms.

„ „ 2 groups of 20 detonators each .... $\frac{.21}{2}$ =.10 „

Total resistance $\frac{.02 \times .10}{.02 + .10}$ =.017 ohms.

„ „ detonators .017 ohms.

„ „ mains .21 „

Therefore total resistance of detonators and mains=.227 ohms.

By experiment the average current required to explode 1 detonator was .35 amps., from which it will be seen that to explode 200 detonators in parallel will require 70 amperes.

Then E=C x R

70 x .27

19.20 volts.

From experience it was clear that in order to explode in practice 200 detonators, considerable more voltage was required; accordingly, 250 detonators were coupled up in 12 groups in parallel 10 groups each having 21 detonators and 2 groups each having 20 detonators. The cables were connected with an ammeter and also with a voltmeter.

The dynamo was started slowly with a gradually increasing speed, until the detonators exploded, with the result that 200 detonators exploded with 25 volts pressure and a current of 70 amperes was recorded.

The difference between the actual and calculated resistances is probably due to the variation in resistance between the individual detonators, which in some cases was as much as .6 ohms., as is seen from the above table.

Whilst the foregoing is useful information as to the actual volts and amperes required, in order to ensure absolute certainty of no misfires due to the inequality of the resistance of the platinum wire in the respective detonators, it has been found advisable to apply 230 volts pressure direct, by means of an ordinary switch, for blasts of any magnitude.

TESTS ON "NO. 6 CURTIS AND HARVEY" HIGH TENSION DETONATORS.

A large number of these detonators were tested, with the following results:—

Average pressure to explode 1 detonator=47 volts.

Resistance of 1 detonator, 1,000,000 ohms.

Therefore current in amperes required to explode 1 detonator,

$$\frac{47}{1,000,000} = .000047 \text{ amperes.}$$

From the above data, and from practical working with a magneto machine, it was very clearly demonstrated from the point of view of misfires that high tension detonators are unsatisfactory. It is unsafe to pass a low current through, and test before firing with a galvanometer; so that there is far too much uncertainty, and accordingly high tension detonators were never used.

From the lantern slides, which clearly demonstrate the results and the destructive energy of the explosion, it can be seen that success can be obtained by electric firing. It must also be understood that extreme care is required—the premature exploding of a mine may very easily cause the loss of a number of lives, especially where numbers of men are working in a comparatively small area.

The following written instructions were given to foremen and powdermen, and as possibly they may be of use to others doing similar work, the author gives them in detail:—

BLASTING BY MEANS OF ELECTRICITY.

(1) The switch has always to be turned to "off"; the key must never be left on the switchboard.

(2) When the time has arrived, the head powderman will give the signal for the horns to be blown and all workmen in the vicinity will move to safety.

(3) The main cable under no consideration may be left connected to the explosives.

(4) The powderman standing by the explosives, having ascertained that everyone is clear, will connect the shunt cables on to the main cable, and then walk to the powderman at the firing switch; the switch powderman will say, "Are you ready?" and the reply will be (provided all is clear) "Fire."

(5) When blasting has to be done in several places, workmen must be kept safe from all places, so that if by any chance any mistake is made in firing the wrong charge, no harm is done in any way.

(6) In the event of a short circuit, the switch must be turned off, as shown by the arrow, and the key removed. The cable must be disconnected at the switch and at the shunt cables. The short circuit can then be searched for.

(7) In the event of any powdermen being absent, due to sickness or otherwise, no blasting may be done until the day or night foreman has been told; the foreman will make temporary arrangements and inform the Engineer-in-Charge.

(8) After the blast the horns will continue to blow until the powdermen have examined the place blasted, and reported that all is satisfactory.

(9) These instructions must be strictly carried out.

The instructions were made as simple as possible, the object being to place the responsibility and authority in as few hands as possible. In a very short time blasting operations were carried out by the men like soldiers at drill.

Electric Firing.

The main cable was 7/16 S.W.G., the shunt cables being 3/20 S.W.G., and No. 6 Curtis and Harvey Low Tension detonators were used. Before firing, the circuit was always tested with a galvanometer, all charges being always connected up in parallel.

If blasting of any magnitude has to be done, it is advisable to run a small dynamo, and use low tension detonators.

Submarine Blasting.

The removal of pier heads and entrances to the graving docks resolved itself into a sordid question of pounds, shillings and pence. A very brief glance demonstrates that to remove them under cover of dams is out of the question, on account of the prohibitive cost. It was decided to remove the pier heads down to 14 feet above O.D.S. level, salving all the valuable granite quoins, coping, etc., and then to blast effectively all the remaining masonry with deep holes and heavy charges.

Space forbids dealing with this in detail, so it is intended to deal with it only briefly.

A very clear view of this drilling on the island, between the Union Dock and the East Graving Dock, showing the entire system of four large F. 24 Ingersoll-Rand drills working with both reheaters, was shown on a lantern slide.

The material to be removed consisted of an island with a granite skin and concrete backing. Holes were first drilled in the granite skin, in a diamond pattern, 18 in. from the face and 2 ft. apart and 20 ft. deep. These were filled almost to the top with cheddite in zinc watertight canisters with charges of 10 and 5 lbs. weight. The inside diameter of the canisters was 2 in., the overall diameter was 2¼ in., and the length of the 10 lb. canisters was 7 ft. Taking a fair average, there were 17 lbs. of cheddite in each hole, but a good deal depended on the material and the work to be done. In the granite caisson check, in which there were granite stones up to 10 tons weight, three 20 ft. holes were drilled, and 75 lbs. of cheddite put in, or 25 lbs. of cheddite per hole. The "nature" of this granite was destroyed by the blast, and it was very like shortbread.

After having blasted round the periphery, and dealt with the granite sink, at the same time reducing the area, preparations were made to blow the remaining portion of the island in one large final blast.

The area of the island was 640 sq. ft. 66 holes were drilled 20 ft. deep, and 1,135 lbs. of cheddite were put in, which gave slightly over 17 lbs. of cheddite per hole; the number of detonated charges was 167. All holes were filled up with cement grout, which confined the gases and added considerably to the effective force of the cheddite.

There was a mat of 3 ft. of water on the top of the masonry at the time of the explosion.

It must be understood that the object was to destroy and smash up the masonry, so that a bucket dredger would have no difficulty in dealing with the old masonry pier heads at a later date.

This blast (see lantern slides) was most successful, no damage being done in any way and no concussion to the walls or to shipping in the dock; at a distance of 200 ft. from the blast no vibration could be felt. In this blast, 1 lb. of cheddite was required to destroy 1 ton of masonry.

From experience gained, it is the author's opinion that the amount of explosives used has nothing to do with the vibration or the wrecking of surrounding property provided the amount of explosive is distributed throughout the area to be blasted, and the holes are so centred that only sufficient explosive is put in to wreck that area. Only experience can determine the amount of explosive to use, as there are so many factors

to take into account, such as the material, quality and size of material, condition of mortar in the joints, etc. Also, it is most important to remember that an island is requisite, as if the wall is backed up by earth, any superfluous energy will be transmitted through it to surrounding property.

In the wiring of these submarine blasts, it is absolutely necessary that the insulation should be perfect. At the junctions of all the groups of detonator wires on to the auxiliary cables, the joints were taped and coated with Chatterton's compound and finally put into small wooden boxes, 5 in. x 4 in., without lids and run in with pitch.

A very large number of big blasts were carried out, and it speaks well for the foremen and powdermen that all were brought to a successful issue. There is a good deal of anxiety connected with them, as in the event of a failure it is a very serious matter indeed, as the problem would be how to deal with half a ton of a high explosive, all detonated, distributed over an area and grouted in. However, " it is no use crossing your bridges until you meet them," and it is the author's desire never to have to cross that bridge.

The old masonry removed by dredging worked out at 4 tons of masonry blasted for each one pound of cheddite.

During the whole of these blasting operations a total of 15 tons of explosives were safely handled, and in 27 weeks' work a total of 63,420 lineal feet (almost 12 miles) of holes was drilled in old masonry, being a little under an average of half a mile a week, the best week's work having been 5,041 lineal feet, and the most done with one drill by two men in a day of 10 hours being 7 holes 24 feet deep, representing a total length of 168 feet of hole drilled.

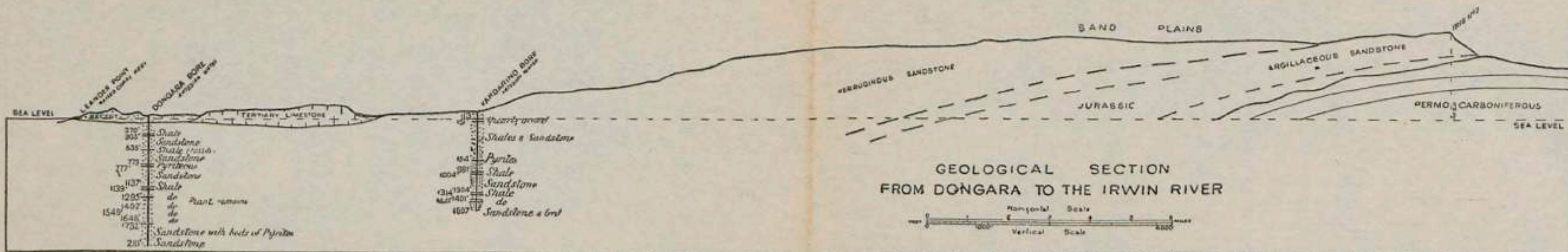
Discussion.

His Excellency the Governor of Western Australia, Sir Gerald Strickland, said that there was no doubt that there were points of similarity between the estuaries of the River Mersey and the Swan River And this fact made him feel that they were forutnate in having amongst them, in Mr. Ramsbotham, an engineer whose experience had been gathered on the Mersey and whose next achievements were to be on the estuary of the Swan River. There was, he thought, nothing more noble or more fascinating than facing the problems of Nature, and, without humbug or equivocation, meeting the laws of Nature fairly and squarely. During his official career he had had frequently to attend to administrative engineering matters. He said that in building a dock at Fremantle, lessons could and should be taken from other shipping dock ports—lessons in regard to the need of making space provision not only for present-day ships, but for the larger ships of the future. The size of modern steam-

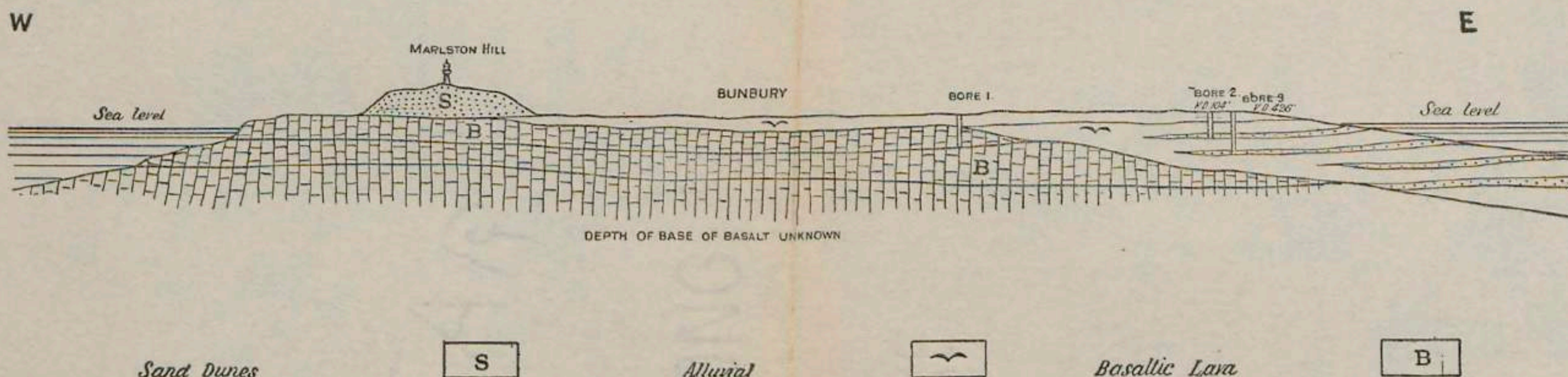
ships was growing apace, although he considered that growth was not unlimited. A limit was being placed on the growth of steamers by the locks of the Panama Canal, these locks being 110 ft. in width and 1,000 ft. in length. These locks would be able to accommodate vessels up to a tonnage of 45,000 tons, and if a vessel were built like a box, even up to 65,000 tons. The size of ships was increasing like a thief in the night. In his own college days vessels such as the "Servia" and the "City of Rome" had been the largest vessels afloat, and yet he firmly believed that at any rate half of those present that night would live to see 65,000 ton ships coming to Australia. Mr. Ramsbotham had told them that Fremantle as a port was pre-eminent, but he (the speaker) did not think that Fremantle was without a rival. She had a rival in the port of Hobart, which was one of the most magnificent ports in the world, the deep-water accommodation there being excellent. Melbourne might get depth for steamer berthing, but Sydney never would. The Panama Canal was going to bifurcate the trade of the world, and there arose the question as to which port was the front gate of Australia. Sydney was not, but Fremantle was. Fremantle realised the position only about twelve years ago; the combined brains of the late C. Y. O'Connor, Sir Winthrop Hackett, and Sir John Forrest had provided a harbour at Fremantle, which at the time was considered extravagantly large and unreasonably expensive. Already the harbour was becoming too small for the traffic, and he verily believed that if in a period of a few years we were unprepared to receive, within 20 miles of Perth, ships of 60,000 tons, Fremantle would not be the "front door of Australia." Whether it would be Hobart or Melbourne could not be said. It resolved itself into a race of brains and finance, and called for "pulling together." As he had already said, there were lessons to be gained from other ports. He cited the case of the harbour at Malta, now one of the most beautiful in the world. During his term of office there a movement was commenced for the transference of the vessels of the British fleet from Malta to Gibraltar, due to the then insufficient accommodation of the harbour. Steps had been taken in time to prevent the extinction of Malta as a port of any importance, and to-day they had a fine harbour and incomparable dockyards there. He would like the people of Western Australia, and especially the engineers of Western Australia, to deal with their harbour problem years in advance and so prevent Fremantle running the risk of not even gaining first or even second place. In conclusion, Sir Gerald expressed keen appreciation of Mr. Ramsbotham's paper.

Mr. J. F. Ramsbotham in reply said:—I have to thank His Excellency the Governor, Sir Gerald Strickland, K.C.M.G., our President, and the Members of the Western Australian Institution of Engineers, for the very kind reception my paper has received. Sir Gerald Strickland's remarks on the opening of the discussion leave much thought for the thinking man, and he conveys an impression that these are times when

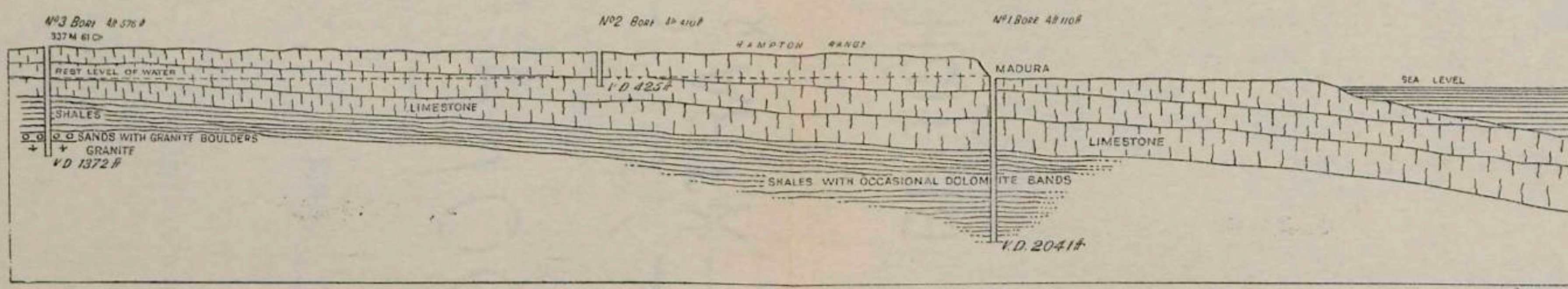
great care must be exercised in the development of all Australian ports. On being appointed to my present position, I requested the Agent-General to write to all shipowners trading in the Southern Hemisphere, asking them to forecast their building programmes ; they one and all advised the Agent-General that the ships of the future would materially increase. This being so, Sir Gerald Strickland's remarks are all the more pertinent, and to my mind the time is ripe for serious consideration and provision for the future : these provisions are not to be lightly considered, as they will affect all the main ports of Australasia. Time after time the Mersey Docks and Harbour Board have completed large and costly schemes, and yet their hand has been forced to undertake new works by increasing trade, competition, and the increased size of steamers. At the present time every port in South America is spending many millions on equipment and increased size and depth of harbours. To my mind that is the key to the whole matter. If Australasia is going to develop, as assuredly she is destined to, the whole problem of docks, equipment, depth of harbours, must be dealt with in no parsimonious spirit, and, what is more, settled in the very near future. Otherwise her great rivals will outstrip her in the great race of production of raw materials, and a check once administered is very hard to rectify. Harbour undertakings are essentially expensive, but they are a flea-bite compared with the check administered to a continent by those who hold the destiny of her future in their hands. As regards the Panama Canal, the size of locks 110 feet wide and 1,000 feet long does not strike one as at all excessive, and I look forward to the day when they will be obsolete. In reply to the President on the percentage of sand pumped, the record at Liverpool is about 40 per cent., the average being for good free coarse sand about 20 per cent. In reply to Mr. Shields, my experience in dealing with mud has not been in raising it, but in getting the mud to settle after having been raised, the same applying to fine sand. In reply to Mr. Haynes, I invite him to come over and see the Fremantle Graving Dock, as a personal visit will more readily answer his questions.



GEOLOGICAL SECTION FROM DONGARA TO THE IRWIN RIVER



Geological Section of Bunbury.



Geological Section from the sea coast to No. 3 Bore at 337 M.P. Transcontinental railway survey.

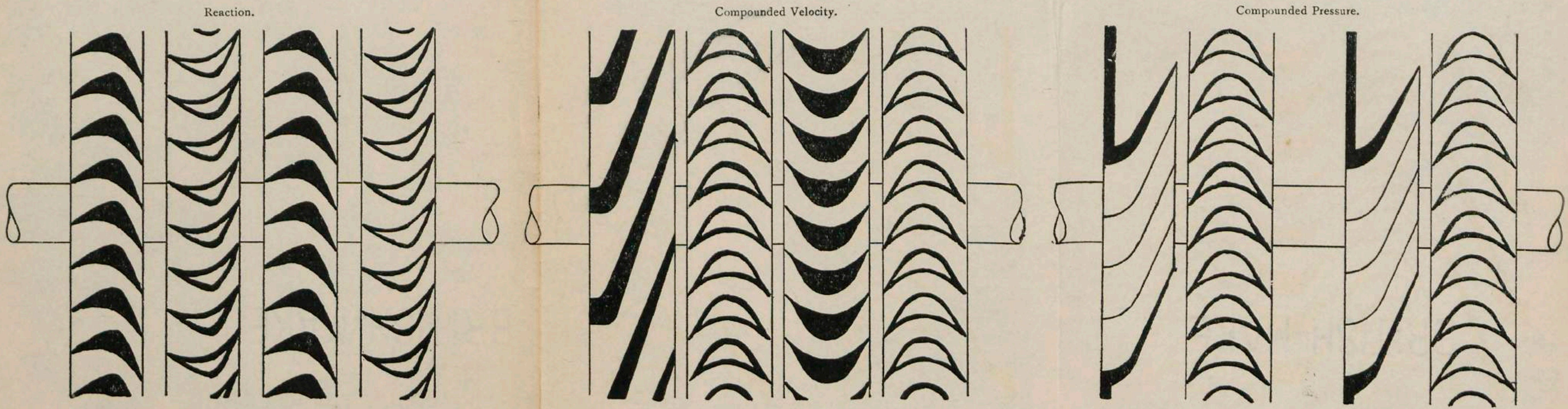


Fig. 1.—Types of Blading.

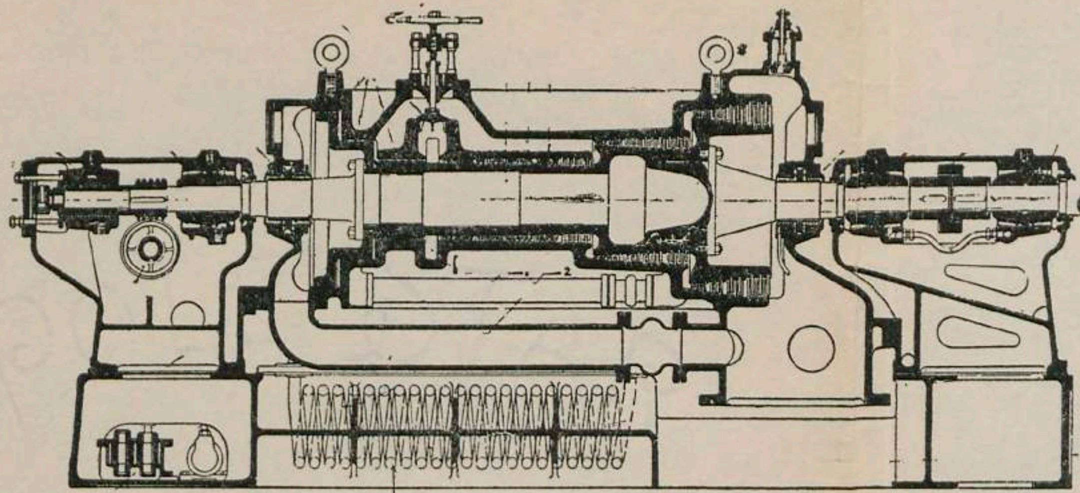


Fig. 2.—Section through Single flow re-action type Turbine.

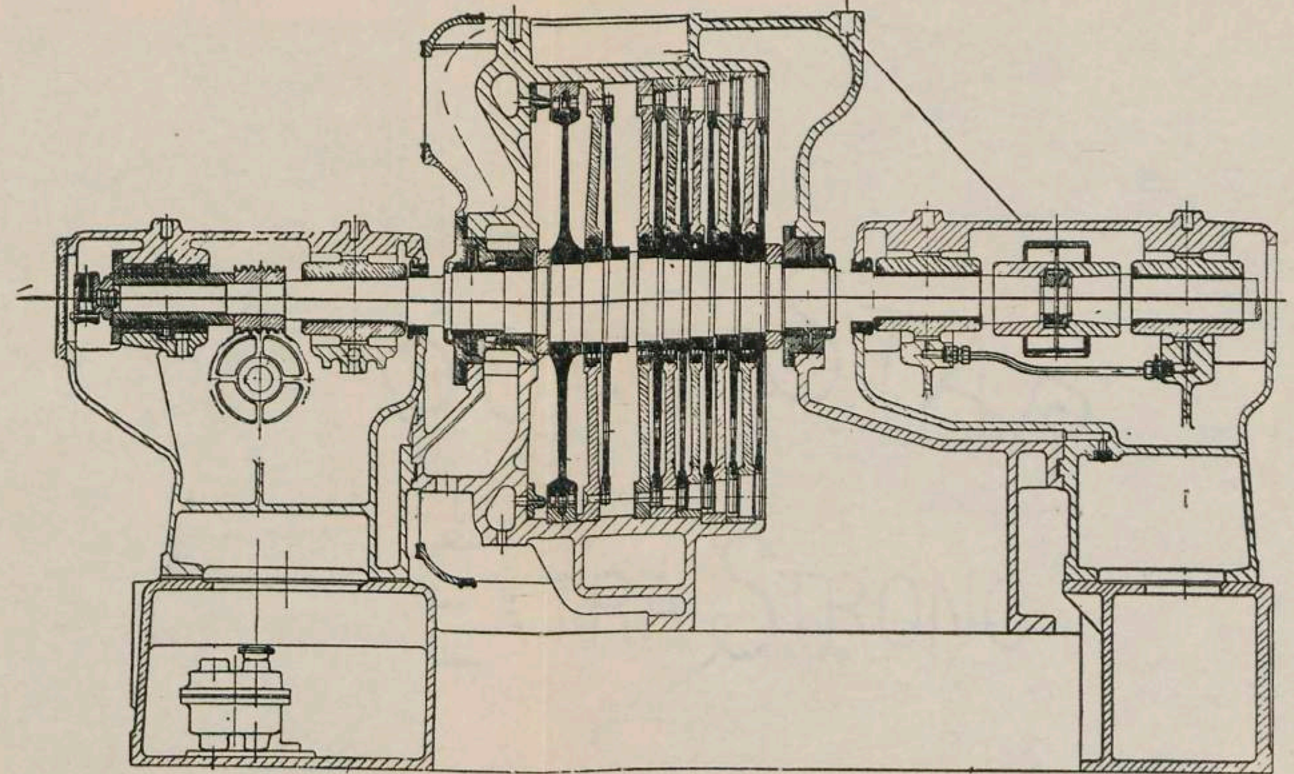


Fig. 4.—Section through Westinghouse Impulse type mixed-pressure Turbine.

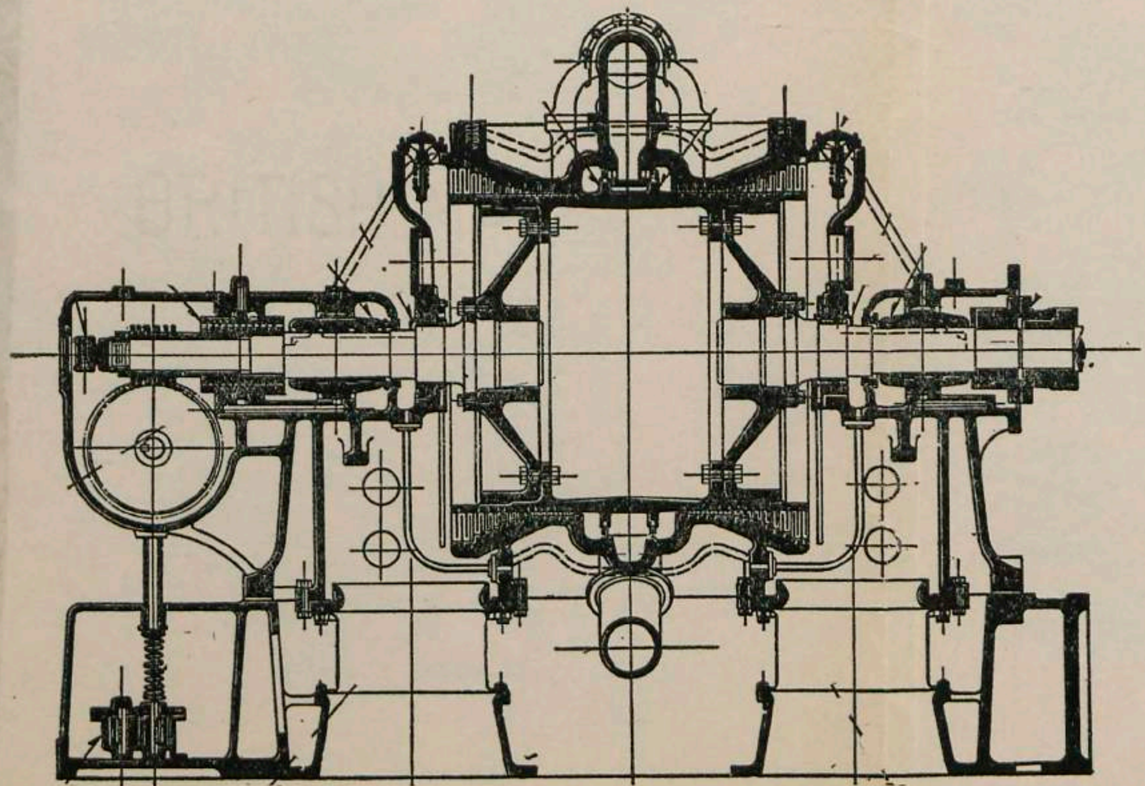


Fig. 3.—Section through Double flow re-action type Turbine, with high pressure impulse portion.

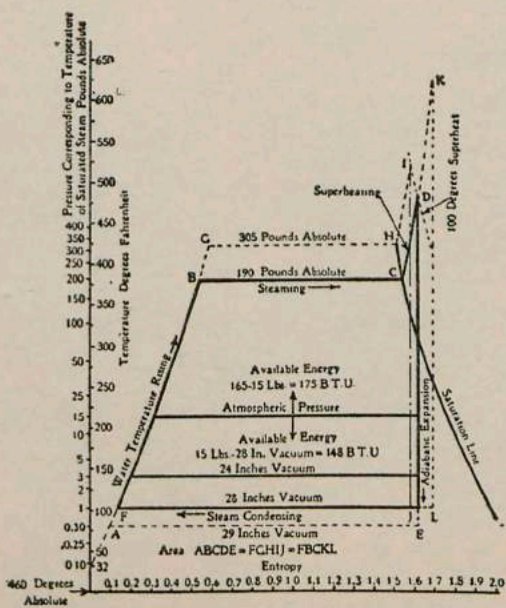


Fig. 5.—Temperature Entropy diagram for steam.
Elec. Jnl.]

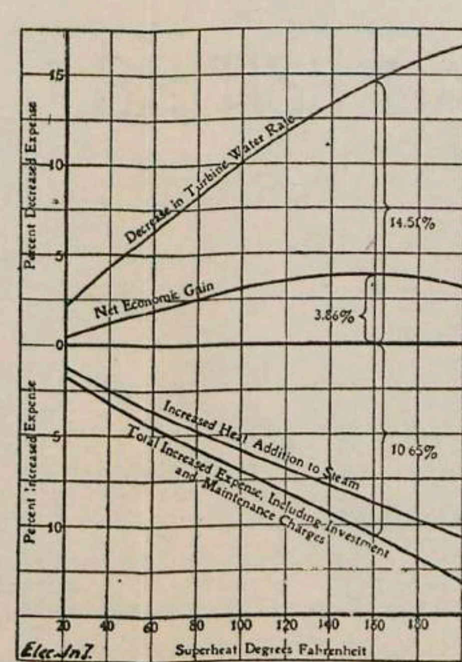


Fig 6.—Economic value of Superheat at full load operation.

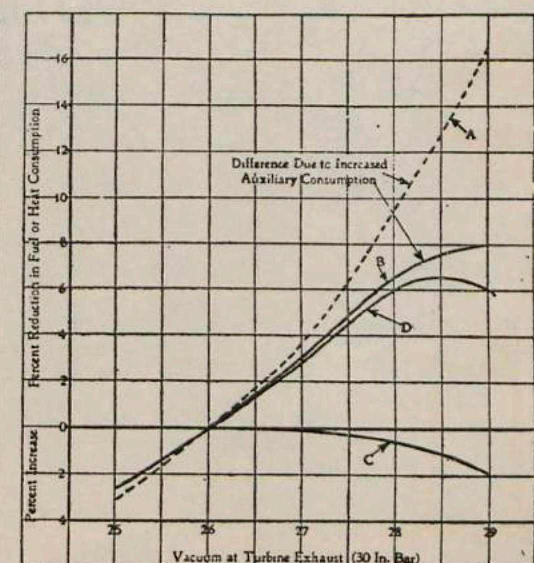


Fig. 7.—Relative value of different vacua on ultimate Plant-economy.
Elec. Jnl.